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ELECTRICAL CATECHISM

AN INTRODUCTORY TREATISE ON ELECTRICITY AND ITS USES

BY

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SECOND EDITION, CORRECTED AND REVISED

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PREFACE TO SECOND EDITION.

In this edition, the opportunity has been taken to revise many sections that had become obsolete, to correct a few errors which crept into the earlier edition, and to add considerable information. Changes of greater or less magnitude have been made in over two hundred sections. The index has been amplified correspondingly. More than sixty new cuts have been added or substituted for those obsolescent. The Appendices, added in this edition, will be found to contain much information in convenient form.

The writer realizes that some chapters might have been further enlarged and new ones added, without exceeding the scope of an introductory discussion. It is believed, however, that the work as now presented, illustrates the practice and beliefs of to-day.

Minneapolis, September, 1908.

PREFACE TO FIRST EDITION.

The work here presented is a revision and enlargement of the *Electrical Catechism,* of which the first instalment appeared in *Electrical Industries* in February, 1895, and which has continued without interruption through succeeding volumes of that periodical and its successor, the *American Electrician.* It is designed to answer the numerous questions that continually come up in the minds of those who come into contact with any application of electricity. The topics are selected from personal inquiries and letters and from the queries noted in electrical papers, these being supplemented by others intended to prepare the way and to make the treatment more consecutive and comprehensive.

The writer has aimed to present in simple non-technical language the information sought by electrical workmen, superintendents, engineers, dynamo tenders, wiremen, motormen, inspectors, mechanics in repair shops and factories; to lay before the general reader the important facts relating to electricity and its various applications without a confusion of technical terms and formulæ; and to give the student a general view of the subject, which may serve as an introduction to the more special and formal treatises. Little is presented which could not be found elsewhere if one knew where to look and had the necessary time and facilities. It is hoped that many who have not the time or opportunity to study the more formal books will here find some of the desired knowledge presented in convenient form and attractive style. The copious index at the end of the volume renders the whole easily accessible. Limitations of time and space have crowded out many topics of interest, but the material presented may be considered as reliable. While it is believed that no inaccurate statements are made, the publishers and the writer will appreciate the notice of any errors that may have crept in and escaped notice.

The writer takes this opportunity to acknowledge his obligations to E. L. Powers, formerly editor of *Electrical Industries,* at whose request the series was begun; to W. D. Weaver, who as editor of the *American Electrician,* urged its continuance, and to whom is due the excellent collection of portraits of the men for whom units were named, some of these appearing now for the first time in print; to J. Zeleny and F. W. Springer for numerous suggestions, and to L. McLaughlin and others for much helpful and patient work in the publishers' offices. Thanks are due also to various manufacturers, whose trade literature has been drawn upon freely for illustrations.

CONTENTS.

CHAPTER I.

STATIC ELECTRICITY.

1. *What is electricity?*

Electricity is either a substance or a force. Some scientists believe it to be the same as the ether, an elastic and extremely thin substance that is supposed to exist everywhere, even between the molecules of solids and liquids, and through the space between the stars. Others think it a force or form of energy; others a condition of the ether. Many believe it to be the fundament of which the elements are modifications. (See Nos. 12, 644.)

2. *What does the word "electricity" mean?*

It comes from a Greek word, *elektron,* meaning *amber.* The Greeks at the time of Thales, 600 B. C., knew that when amber was rubbed, it would attract bits of paper and straw.

3. *If we do not know what electricity is, how can we use it?*

Although the exact nature of electricity is not fully understood, much is known about it. Many laws have been discovered that always hold true. We do not know exactly what gravitation is, and yet we know its laws and how to make use of them.

4. *How many kinds of electricity are there?*

All electricity is probably one and the same. (See also No. 140.) It is sometimes classified according to its motion, as:

(1) Electricity at Rest, or Static Electricity.
(2) Electricity in Motion, or Current Electricity.
(3) Electricity in Rotation, or Magnetism.
(4) Electricity in Vibration, or Radiation.

5. *What is static electricity?*

Static electricity consists of stationary charges, which show themselves by attracting or repelling other bodies.

6. *What is electricity in motion?*

An electric current manifests itself by heating the wire or conductor, by causing a magnetic field around the conductor and by causing chemical changes in a liquid through which it may pass. It is now believed that the electrical energy is not carried through the wire, but through the space around it.

7. *What is electricity in vibration?*

When the current oscillates or vibrates back and forth with extreme rapidity, it takes the form of waves which are similar to waves of light.

8. *Is magnetism a kind of electricity?*

Magnetism is a result of electric currents and under some conditions will produce currents. A common theory is that magnetism is caused by currents of electricity circulating in the molecules or particles of a magnetized substance.

9. *How long has anything been known about magnetism?*

Hoang Ti, a Chinaman, is said to have used a magnet for a compass in 2637 B. C. The Greeks used a magnet or lodestone at the siege of Troy about 1000 B. C.

10. *How long ago was static electricity discovered?*

It is not known. Moses was acquainted with the lightning, and some of the vessels in the tabernacle seem to have been made with a knowledge of electricity. The Temple at Jerusalem was well protected against lightning and was not struck in 1000 years. A Greek philosopher, Thales, about 600 B. C., mentioned that amber (elektron) attracted bits of straw when rubbed. Aristotle, in 341 B. C., wrote about electric fishes that paralyzed other animals.

11. *When was current electricity discovered?*

By an Italian named Volta, about a century ago.

12. *When were electric waves discovered?*

Light has been known since the beginning of the world. Joseph Henry, an American, proved in 1842 that the discharge from a Leyden jar was oscillatory. It was not until 1867 that an English mathematician, Maxwell, proved mathematically that light and electricity were the same. In 1888 Heinrich Hertz proved by experiment that this was true.

13. *Why did the older text-books give so much attention to static electricity?*

Because more was known about it than about currents, and because it was a means of making many attractive experiments.

14. *Is static electricity of any importance in practical work?*

Electrostatic charges are important with pulsating or alternating currents in telegraphy, telephony, power transmission lines, spark coils, lightning, etc. (See Nos. 101, 107, 115 116, 143.)

15. *Why should a practical worker learn about static electricity?*

Static electricity is dangerous in some cases and troublesome in many others, and one should know how to avoid or get rid of it. In other cases it is useful, as in the application of condensers to telephone ringing and talking circuits and in making possible simultaneous telephony and telegraphy on the same line.

16. *In what different ways is static electricity produced?*

By chemical action, by magnetic induction, by heat, by friction, by influence and in some cases by pressure.

17. *How does static electricity show itself?*

By the attraction or repulsion between charged bodies. When static electricity is discharged, it causes more or less of a current, which shows itself by the passage of sparks or a brush discharge; by a peculiar prickling sensation; by a peculiar smell, due to its chemical effects; by heating the air or other substances in its path; and sometimes in other ways.

18. *Is any special or costly apparatus needed to detect static electricity?*

It is, if one wishes to make very accurate and delicate measurements. But much can be learned by very simple and cheap means.

19. *What are some easy ways of producing and showing the effects of static electricity?*

Rub a dry sheet of paper with a piece of dry cloth or with a coat sleeve, and the paper will stick to a table or to the wall for some time.

Pass a rubber or celluloid comb through the hair on a dry or cold day and the hair will stick to the comb. If it is quiet, one may hear a slight snapping noise. The ends of the hair will also stand out as if they repelled one another. If it is dark, one will sometimes see small sparks from his hair, like the sparks from a cat's back.

By shuffling across the carpet on a cold, dry day, and then touching another person or a gas or water pipe, a spark will pass from him and he will get a shock at the same time.

20. *How can one make a cheap indicator for studying static electricity?*

By hanging a small bit of pith or feather on the end of a fine silk thread, or on a fine hair, several inches long.

21. *What is such an indicator called?*

An electroscope, because it enables us to see whether a body is electrified or not.

22. *How is the feather electroscope used?*

If an electrified body is brought near it, the feather will be attracted. If the feather touches it, it will soon be repelled and fly away.

23. *How can a more sensitive electroscope be made?*

Take a dry bottle with a wide mouth; push through the cork a piece of wire, the lower end of which is bent so as to form a square hook; upon this hook, hang a strip of ordinary gold leaf (which may be obtained from a dentist or at a bookstore,) in such a way that the two ends are of the same length and hang flat and close together; place the cork in the bottle and adjust the wire so that the gold leaves do not touch either the sides or the bottom of the bottle. If the electroscope is charged by touching the wire with some substance that has been previously charged, the two gold leaves stand apart as if repelling one another.

24. *What can be learned from the gold leaf electroscope?*

It will show whether a body is electrified; it will indicate to some extent how much charge it has; it will show whether the charge is positive or negative. It will show whether wires are highly charged.

25. *What is meant by a positive or negative charge?*

With the feather or pith-ball electroscope, it is noticed that the feather is at first attracted to the charged body, and is then repelled from it. If one charges the gold-leaf electroscope with a rubber comb that has been rubbed with a dry cloth, the leaves will stand further apart if the rubber is brought near the wire again; but if the rubbed part of the cloth is brought near, the gold leaves come closer together. When dry hair is dressed with a rubber comb, the hairs are attracted by the comb, but they stand apart from one another. This shows that when two substances are rubbed, both are electrified; but the charges are different. It also shows that bodies oppositely charged attract one another, but that bodies similarly charged repel each other. This is analogous to the law that like poles of magnets attract one another, while unlike poles repel.

26. *What is the difference between positive and negative charges?*

It is not definitely known. Many scientists have believed that there were two kinds of electricity; others believe that there is only one kind. If a body contains more than the usual amount, it is said to be positively charged; if it contains less than the usual amount, it is said to be negatively charged. A body is discharged when the positive and negative electricities come together and are neutral-

ized. According to the other theory, a body is discharged, or neutral, when it contains neither more nor less than the usual amount. If electricity is a state of strain in the ether, a body is charged or not, accordingly as the ether in and about it is compressed, stretched, or is neither.

27. *Can electricity be produced by rubbing any two substances together?*

When they are unlike and are insulated.

28. *Does the same amount of rubbing always produce the same amount of electricity?*

No. It depends upon what substances are rubbed. Some are much more strongly electrified than others.

29. *Are some substances always positively electrified by rubbing, and others always negatively electrified?*

When any two substances are rubbed together, one of them is always positively electrified, and the other negatively. The same substance may be either positive or negative, according to the nature of the other substance. Different materials may be arranged in such an order that any one will be positively electrified if rubbed by any substance before it on the list, but negatively electrified if rubbed by any substance coming after it.

30. *Can static electricity be produced equally well by rubbing any two substances together?*

No. It is difficult to find any by rubbing metals together. The presence of moisture lessens the effects. Substances known as insulators become electrified easily, while those known as conductors do not.

31. *Why do not electrical conductors easily become electrified by friction?*

Because, as fast as the electricity is produced, it is carried away and becomes neutralized.

32. *What is the difference between insulators and conductors?*

Conductors are those substances in which electricity travels easily, while insulators do not furnish an easy path. There is no clearly marked line, since no substance is a perfect conductor, offering absolutely no resistance to the motion of electricity; nor is any substance a perfect insulator, absolutely preventing the motion of electricity. Different substances may be arranged in more or less definite order, with the good conductors at one end and with good insulators at the other end.

33. *Give a list of some common substances arranged in the order of their conductivity.*

1, silver; 2, copper; 3, other metals; 4, carbon, charcoal and graphite; 5, acids and salty solutions; 6, animals and plants; 7, pure water; 8, various oils; 9, cotton; 10, dry wood; 11, marble; 12, porcelain; 13, wool; 14, silks; 15, rubber; 16, shellac; 17, paraffin; 18, glass; 19, dry air.

34. *Do these substances always keep in the same relative order?*

No. Their conductivity is affected by various conditions, such as their purity, the presence of moisture and other causes.

35. *If a substance is a conductor for static electricity, will it also conduct current electricity?*

Not always. Any substance that will conduct a current will also carry static electricity. Since the latter is of high pressure and comparatively small quantity, it will travel slowly over surfaces that would not carry any perceptible current of electricity. Static charges will gradually creep along the surfaces of dry wood or glass, substances which are excellent insulators for currents. In fact, the doctors sometimes use wooden electrodes with static machines in order to give gentle diffused discharges to patients.

36. *Is static electricity carried through the body of a conductor or upon its surface only?*

It is generally understood that a static charge is only on the surface. A current generally spreads through the conductor, so that the conductivity for currents varies with the area of the cross-section rather than with the area of the surface.

37. *What is conduction?*

An example of conduction is found by holding a wire or a piece of metal pipe near a belt or other source of static electricity. If it is developing much electricity, one will get a shock through the pipe as strong as from the belt itself. Sometimes a shock will be received from a machine, a line shaft or from a belt-shifter. The electricity comes from the belt, and is conducted by the metal. Static electricity may be carried considerable distances if the conductor is well insulated. The static electricity from dynamo belts sometimes gets over the insulation on the machines into the circuits and is carried along the wires. It is very difficult to get perfect insulation so as to prevent the escape of a static charge, and instruments for measuring static electricity must be designed and used with great care, unless the escape of some of the charge is not im-

portant. An example of conduction of static electricity is suggested in the figure, in which two tin pails are connected by a wire and are suspended by means of dry cords or threads. If one pail is near a belt, a shock may be obtained by touching the other pail. If

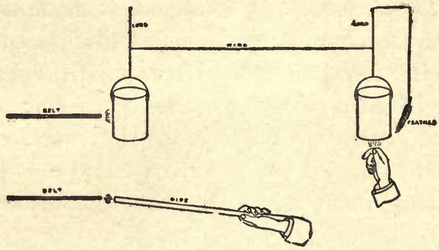


FIG. 37.—CONDUCTION OF ELECTRICITY.

the belt is not generating enough electricity to give one a shock, it may be detected by the repulsion of a small pith ball or a bit of feather held near the pail by a fine thread.

38. *How is static electricity generally obtained for experimental purposes?*

It is generally obtained from frictional or from "influence" machines. The former are common in the older laboratories, but are now being replaced by more modern machines, such as the Toepler-Holtz or the Wimshurst machines.

39. *What is a frictional electric machine?*

A common form consists of a circular glass plate which may be rotated and upon which two leather or felt rubbers press. The rub-

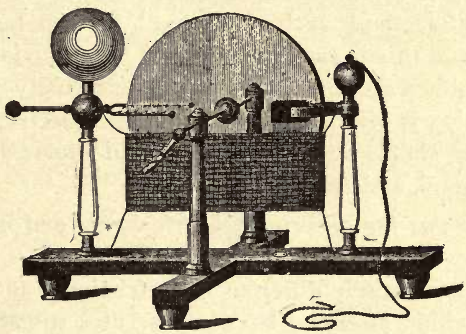


FIG. 39.—FRICTIONAL ELECTRICAL MACHINE.

bers are coated with an amalgam of tin and mercury. When the glass plate revolves, the friction causes the rubbers to become negatively electrified, while the glass becomes charged with positive electricity, which is collected by a number of sharp points on a sort of

metallic comb placed diametrically opposite from the rubbers. The comb and the rubbers are connected, respectively, with two large knobs called "prime conductors," from which sparks or a brush discharge may be taken.

40. *How do Toepler-Holtz or Wimshurst machines operate?*

Their theory is too complicated for full discussion here. They depend not upon friction, but upon electrostatic induction or "influence." They are based upon the fact that oppositely charged bodies attract each other, hence it requires work to move them apart. When the two bodies have a certain charge and are then separated, the work of moving them apart increases the difference between

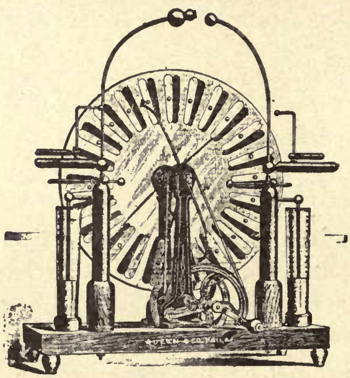


FIG. 40.—WIMSHURST MACHINE.

their potentials. An initial charge is given to the machines by some convenient method, such as a small friction machine or an electrophorus, and this is rapidly increased by induction. Such induction is probably a principal source of the electricity of the clouds. Fuller explanation is given in Mason's "Static Electricity." Directions for making simple machines are given in *American Electrician* of November, 1896, and August, 1897.

41. *Do dynamos for operating electric lights and motors generate electricity by friction?*

No. These are entirely different from frictional and other static machines, and will be discussed later in Nos. 1100 to 1270.

42. *What sort of a frictional machine is used for lighting gas?*

Several forms have been on the market. The style illustrated contains a hard rubber disc that is rotated by means of a crank. One or more pairs of amalgamated pads are pressed against the disc. The charges on the pads and disc are conducted into a condenser

(see Nos. 111 and 112) that forms part of the frame. The machine is charged by turning the crank several revolutions in the direction of a clock, or "clockwise," and then turning it back a short distance. The disc and the frame in which it is supported have a certain amount of play inside the case. When the crank is turned backward, the two terminals of the condenser come into contact with two

FIG. 42.—FRICTIONAL GAS-LIGHTING MACHINE.

binding posts on the case, and the charge in the condenser causes a momentary current to flow through the circuit connected between the terminals *L* and *G*. Induction coils are now used. (See No. 49.)

43. *How is the discharge used to light gas?*

It is used for lighting a number of jets supplied by the same gas pipe which may be in places difficult of access for lighting with

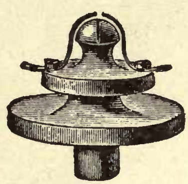


FIG. 43.—JUMP-SPARK GAS TIP.

matches or tapers. Each gas jet has a special tip of lava or other insulating material and carries two wires, which are separated a short distance, and are so placed that a spark passing between them will ignite the gas as it issues from the tip. The wires on the different tips are connected "in series," so that the discharge from the machine will cause a spark or number of sparks to jump across from wire to wire on each tip. The wires are carefully insulated and are

so placed that sparks will not occur at any place except at the gas tips. In operating the device, the gas is turned on and the crank is turned rapidly and then turned back. By this time the gas has filled the pipe and is issuing from the tips. The backward movement of the crank connects the machine with the circuit, and the sparks light the gas simultaneously at all the jets.

44. *Can one machine be used to light more than one set of gas jets?*

Yes. For this purpose a "multiple point switch" is used, by which one terminal of the machine may be connected to any one of a number of circuits. It is customary in buildings without electric lights to "ground" one end of each circuit upon the gas pipe, which thus becomes a common return for all the circuits, in which case one terminal of the machine is also grounded on the pipe. Fig. 42 shows a machine connected to a four point switch, so that it can light the gas on any one of four circuits.

45. *Is it safe to use the gas pipe for the common return?*

It is safer to use a separate wire for the return, especially where the gas lighting device is used in a building lighted by both gas and electricity. The high pressure used in connection with the spark circuit is liable to cause a spark to jump to the other circuit, and so occasion risk of danger from fire. The insurance rules require that "Electric gas lighting must not be used on the same fixture with the electric light. The above rule does not apply to *frictional* systems of gas lighting." It is better to have the gas lighting circuit entirely insulated from the electric lighting circuit.

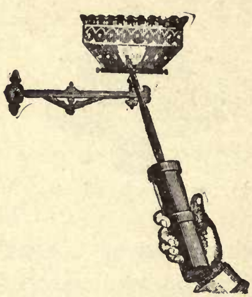


FIG. 47.—HAND DYNAMO GAS LIGHTER.

46. *How many jets may be lighted at once by a frictional machine?*

Machines 8 in. in diameter will light from one to thirty-five burn-

ers at once. Some machines 12 ins. in diameter will light as many as one hundred jets in one circuit.

47. *Is there a frictional machine for lighting single jets?*

Such are sold at $3.50 to $6.00, having in the handle a small frictional generator operated by the thumb. A later device contains a battery which heats a wire to incandescence.

48. *How much do the frictional machines for multiple gas-lighting cost?*

Frictional electric gas lighting machines cost from $30 to $70. The multiple jump-spark burners cost 25 to 50 cents each.

49. *Is there not a cheaper method of lighting gas by electricity?*

Yes. When single jets, or groups of less than ten are to be lighted, it is cheaper to use a battery with a "spark" coil. Sometimes "induction coils" are used instead of frictional machines for lighting as many as twenty-five jets at once.

50. *What is an induction coil?*

It consists of two coils of wire wound around a bundle of iron wires. One coil has a large number of turns of fine wire. The other coil has a comparatively small number of turns of coarse wire and is connected to a battery through a vibrator or interrupter that closes and opens the circuit rapidly, so as to make the current

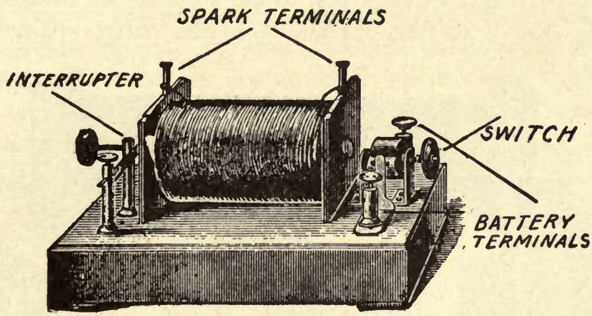


FIG. 50.—INDUCTION COIL.

pulsate. The iron core is magnetized every time current flows, and loses it when the current stops. The changing magnetism "induces" in the fine wire coil a small current at very high pressure, which will jump across considerable distances and may be used for multiple gas lighting or other purposes. These are listed at from $4 to $75.

51. *What is the difference between an induction coil and a medical coil?*

A medical coil is a variety of induction coil whose secondary or

high pressure winding has fewer turns of wire than the secondary of an induction coil intended for giving sparks. The medical coil, therefore, gives a lower pressure. Such coils usually have some sort of regulating device, commonly a sleeve or tube that can be slipped over the iron core. The currents induced in the tube weaken

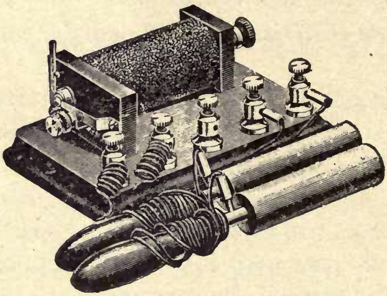


FIG. 51.—MEDICAL COIL.

the magnetic induction through the fine wire coil, and thus reduce the intensity of the shock. Electro-medical treatment should be taken with great caution, as harm may come from improper use.

52. *What is a spark coil?*

It consists of a single coil of several hundred turns of wire wound about a core of small iron wires, which become magnetized when the circuit is closed, so that current from the battery passes through

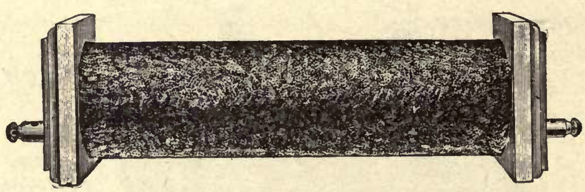


FIG. 52.—SPARK COIL.

the coil. When the circuit is opened, the core loses its magnetism and induces a high pressure in the coil, so that a strong spark appears at the place where the circuit is opened.

53. *How is a spark coil made for lighting gas?*

For the core, make a bundle of soft iron wires, about No. 19, cut to a length of 8 ins. or 10 ins. and pulled straight; make the bundle about ¾ in. in diameter. It will be better if the wires are shellacked or varnished before being tied together. Cover the core with several layers of dry or paraffined paper; put on two suitable heads of wood or fiber; wind on about seven layers of No. 14 or No. 18

annunciator wire; bring the ends out to suitable binding posts on the ends of the spool, and cover the coil with binder's cloth or with stiff paper. If double covered magnet wire is used instead of the annunciator wire, the whole coil should be boiled in paraffine to improve the insulation.

54. *What kind of gas jets are used for lighting with a battery and spark coil?*

Several varieties are used. In the "ratchet" burner, the gas is

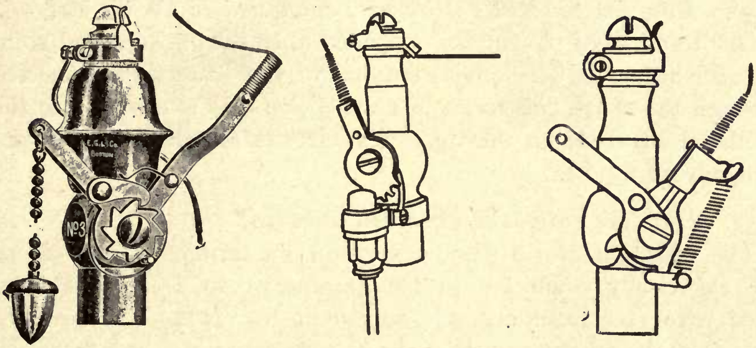


FIG. 54.—ELECTRIC GAS LIGHTING BURNERS.

turned on and off by pulling the chain; the same motion makes the spring wire wipe against an insulated hook near the gas jet and thus closes the circuit; as the spring snaps past and breaks the circuit, the spark lights the gas. In the "stiff pull" burner, a pull turns the gas on and lights it; an upward push turns it off. To increase the life of the battery, the best lighters make a spark only

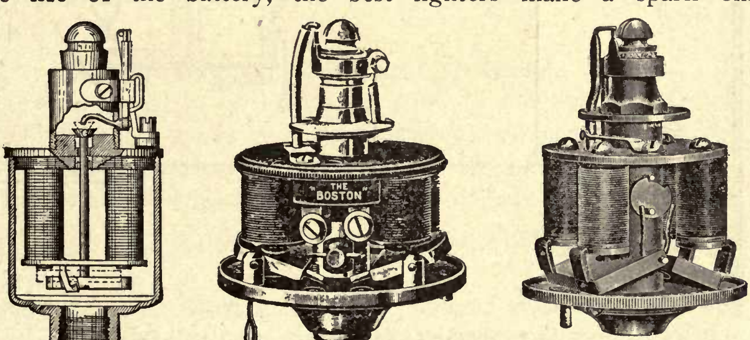


FIG. 55.—AUTOMATIC BURNERS.

when the gas lights. Some cheaper lighters have one cock for turning the gas on and off, and a separate device for making the spark.

55. *What are automatic electric gas burners?*

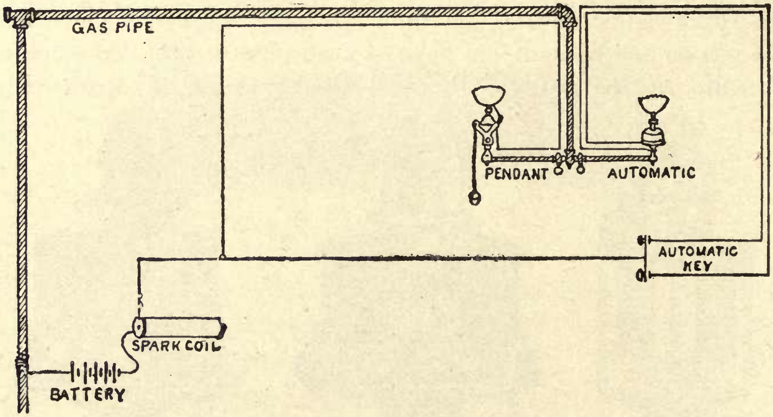
An automatic electric gas lighter is operated by an electromagnet that turns on the gas and causes sparks near the tip. In some early automatics, the same magnet shut off the gas when the key was closed long enough. Modern automatics have two magnets controlled by separate keys. The gas is turned on and lighted by pressing a white key, or is turned out by pressing a black key.

56. *How are pendant gas burners connected to the circuit?*

One terminal of the battery is connected to the gas-pipe and so to the gas burner. The other terminal of the battery is connected through the spark coil to an insulated wire that is attached to the insulated electrode on the tip. The circuits are shown in the accompanying figure.

57. *How are automatic burners connected?*

The vibrating arm of the burner and one terminal of the battery are electrically connected to the gaspipe or to a separate insulated wire (see insurance rule quoted in No. 45). The insulated wire from the other terminal of the battery passes through the spark coil to the two push-buttons, whence two insulated wires go to the burner. Here one circuit passes around an electromagnet which turns on the gas and ignites it by means of the spark where the cir-



FIGS. 56-57—GAS-LIGHTING CIRCUITS.

cuit is broken at the jet. The other circuit passes around another electromagnet which turns the gas off when the dark button is pushed. The two circuits unite beyond the coils and connect with the gas-pipe, or with an insulated return wire to the

battery, as shown in the figure. For convenience, the two push-buttons are white and black, to indicate whether the room will be

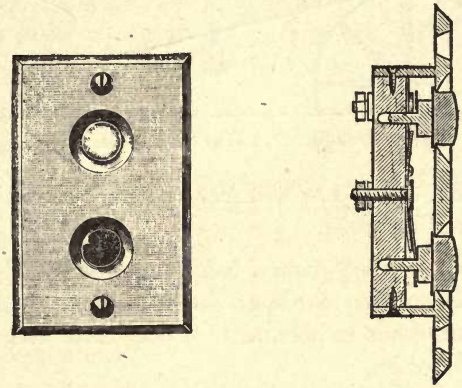


FIG. 57.—GAS-LIGHTING PUSH-BUTTONS.

lighted or darkened. It is also desirable to place the switch so that the light button will be on the upper side and the dark button below, so that one will push the upper button to turn the light up or push the lower button to lower the light.

58. *For what purposes are static machines used other than for gas-lighting?*

They are used largely for medical and educational purposes. Many important investigations in connection with lightning arresters and in other lines have been carried on with the help of static machines in laboratories connected with electrical manufactories and colleges.

59. *Is the electricity on belts caused by friction?*

It is caused partly by internal friction in the belt as it bends around the pulley; partly by friction between the belt and the pulley; partly by friction between the belt and the air; largely by induction as the charges are separated by the motion of belt.

60. *Why does the belt give more electricity on some days than on others?*

When the air is moist it is not so good an insulator. The belt also becomes more or less damp and allows the electricity to pass along to the pulley and escape.

61. *How can a person tell whether a belt is charged with electricity?*

A spark or bluish colored brush will pass from the belt to one's

hand or to any piece of metal held near, if the belt is charged. If one stands near a belt that is highly charged, the electricity will cause

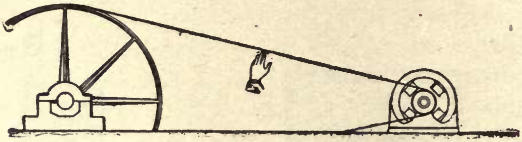


FIG. 61.—ELECTRICITY FROM BELT.

his hair to stand out and he will feel a peculiar sensation, as if he had brushed against cobwebs.

62. *Is the electricity from a belt dangerous?*

One may sometimes obtain an uncomfortable shock, but it is not considered dangerous to persons. It may cause trouble to electrical dynamos and motors.

63. *Why is the belt electricity dangerous to dynamos and motors?*

Because it sometimes jumps through the insulation, causing a spark. The regular current from the machine is not ordinarily of high enough pressure to jump through insulation, but it can follow a spark. Sometimes the static electricity from the belt charges the iron frame of the machine, jumps through the insulation to the wires, and so "grounds" the machine. On arc light or alternating-current machines using high potentials, this makes it dangerous to touch even the frame when the machine is running. Under some circumstances this may cause the machine to become short-circuited, and so to burn out.

64. *Is electricity from belts liable to cause fires?*

A number of cases are known where fires were started in this way. The sparks have set fire to the vapors of benzine or gasoline used for cleaning type in printing offices, or for cleaning clothes in tailor shops. Such sparks might also set fire to oily waste or other inflammable material.

65. *Are fires caused by frictional electricity other than that from belts?*

Several fires have occurred in dressmaking establishments from sparks caused by friction when cleaning dresses with benzine.

66. *What causes the peculiar smell like wet matches often noticed near belts that are charged with static electricity?*

The smell is that of the ozone that is formed from the oxygen of the air by the electric discharge.

67. *Is this smell dangerous or poisonous?*

It is not poisonous, but healthful. It is believed to be a source of danger, since oily waste and similar substances will ignite spontaneously more easily if much ozone is present. Fires once started will spread faster when the air contains ozone.

68. *Can any practical use be made of this ozone?*

It helps make the engine room or central station a healthy place to work. No commercial use seems to have been made of the ozone developed by belts, although ozone is frequently made in special apparatus for medical purposes. Ozone is also used for bleaching, disinfecting, drying and seasoning, for purifying water and for other purposes where a strong oxidizing agent is desired.

69. *How is ozone made?*

An ozone generator usually consists of two conducting surfaces, which are well insulated from each other and placed at such a distance apart that when oppositely charged there will be a "silent discharge" between them as the electricity slowly passes from one to the other across the intervening air. When air passes between such surfaces the oxygen of the air (whose molecules each consist of two atoms), is dissociated and recombined into ozone, each molecule of which contains three atoms. The ozone has a strong tendency to break up, and the atoms thus set free unite with or "oxidize" other substances. The exact process by which the oxygen is changed into ozone by the action of electricity is not completely understood.

70. *What are electric belts?*

The expression is used in three distinct senses. First, in reference to belts that develop considerable quantities of static electricity, as considered in Nos. 59 to 66 above. Secondly, it is sometimes used as a name for special brands of belting of selected material of uniform weight, width and thickness, which have been developed for operating electric or other fast running machinery. Thirdly, the term is used for devices intended for wearing on the human body and supposed to cure all manner of weakness and disease.

71. *Are electric belts of any real medicinal value?*

Manufacturers and vendors of electric belts have many authentic testimonials of undoubted cures that have followed the use of electric belts. In most such cases the cures are due to the expectation of the wearers and to that extent only are due to electricity. The great success of such articles for the most part simply illustrates the immense influence of the mind over the body; and a red string tied

to a shark's tooth would do equally well, could it be associated with electricity in the mind of the wearer. A few belts really yield electricity.

72. *What are electric castors?*

These are castors with wheels made of glass or other insulating material. They are supposed to keep the electricity of the body from escaping to the earth. Therefore, if one sleeps on a bed with glass or porcelain castors, or on one with the feet set on glass knobs, he will sleep better and will get well. The recovery comes from the better sleep, which is a result of the confidence in the effectiveness of the "invaluable" device. If one pays a good round sum for such devices, he believes they will help him; they do help, if he has sufficient faith.

73. *Are electric belts and castors to be commended?*

They certainly will not harm anything except the pocketbook, and to that extent are preferable to drugs and patent medicines.

74. *Why do printers object to static electricity?*

When the paper is electrified, the sheets stick together so that it is more difficult to separate them in feeding to the press; they stick to parts of the press, so that it sometimes requires two men to feed the paper to the press; sometimes the paper will stick to the cylinder or blanket so tightly that it is torn in removal; in cylinder presses, the paper will sometimes stick to the fly and necessitate a stop with loss of time; it does not deliver regularly and will not pile evenly, so that much time and stock are lost in preparing the work for folding or cutting; the sheets stick so tightly together that the fresh ink offsets and smuts; the presses must be run slower to avoid trouble; sometimes the pressmen receive severe, or at least, annoying shocks.

75. *What causes the static electricity about printing presses?*

Part of it comes with the paper, which becomes highly electrified during the process of calendering to such an extent that sparks 6 ins. or 8 ins. sometimes jump from the paper, such electrification making it uncomfortable for the workmen. Some of this electricity remains on the paper when it is packed, the amount varying with the quality of paper, the treatment it receives at the mill and the dryness of the warehouse. The paper also becomes electrified in the printing office, as the sheets are drawn over one another in feeding the press or in other handling. The press seems to become electrified, especially when the ink is sticky, the electrification seeming to be due partly to the tearing apart of the ink. Probably some of the electricity is

due to the bending and stretching of the paper under the type and against the blanket.

76. *How can static electricity be removed from a printing office?* A reasonable amount of moisture in the air is the most common cure. The moisture from the air makes everything slightly damp, and water is a good conductor for static electricity. The result is that the positive and negative charges come together and become neutralized, much of it going to the earth. Too much moisture, however, is apt to cause trouble by rusting. A common method is to "ground" the presses and also to provide special conductors for taking the static electricity from the paper to the earth. Connection with the water or gas-pipes will usually give sufficient connection with the earth, although it is better in some cases to connect with a pipe or rod driven into the earth to a depth where it is permanently damp.

77. *How is steam applied for removing the static electricity?* Where the paper is fed from a roll to a cylinder press, steam is sprayed directly upon the paper through fine holes in a steam pipe close to the press where the paper enters. In other cases the steam

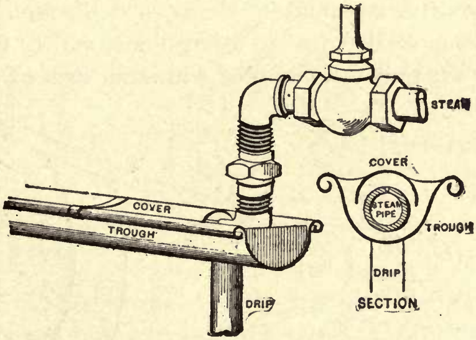


FIG. 77.—STEAM SPRAYER.

is diffused so as to form a sort of mist or small cloud of vapor. The sketch shows one method of applying from a pipe 6 ins. below the tapes of the delivery of a cylinder press so that the paper is moistened as it leaves the cylinder.

78. *How can the electricity be removed when it is desirable not to moisten the paper?*

A brush of fine wires arranged to trail upon the paper will collect much of the charge, and if well connected with the earth will carry it off. Hot air has been applied successfully for this purpose. The paper may also be passed between "grounded" metallic rollers, which

will take off any charge that may be on the paper as it enters the press.

79. *How can hot air be used to remove static electricity?*

Very hot air is a fair conductor for electricity. Any current of air will dissipate a charge, since each particle of air coming in contact with the charge takes up a small part of the charge and carries it away. A method in successful use is to place under the feed-board of the cylinder press a gas-pipe in which have been drilled a number of holes one and a half inches apart, and large enough to give gas flames about an inch high. The current of warm air arising from this will dissipate the electricity.

80. *Why is the electricity worse on a cold day?*

Probably because there is not so much moisture in the air when it is cold. Consequently everything is dryer and is less able to conduct the charges away. Cold air is a better insulator than hot.

81. *How can electricity be removed from belts?*

A common method is to fasten near the belt a number of sharp metallic points which are connected with the ground. One way of doing this is to drive a number of sharp tacks through a piece of tin, or to solder some small wires to a large one, and to fasten the row of points near the pulley so as to be within an inch of the belt. An-

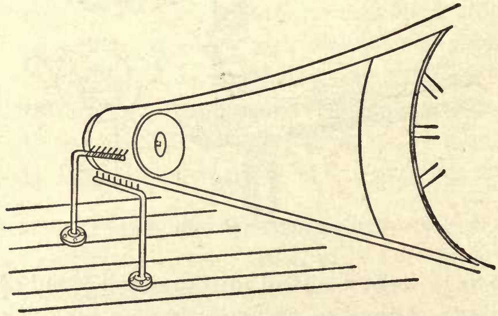


FIG. 81.—STATIC COLLECTORS.

other method is to stretch a wire lengthwise of the belt and a few inches above it. Still another plan is to fasten a bundle of fine wires, such as are used in lamp cord, a short distance above the belt. Any of these devices will take most of the electricity from the belt, if electrically connected with the ground and if the points are close enough to the belt. Of course, care must be taken that they do not become caught in the belt. (See also Nos. 106 to 109.)

82. *What methods are used for taking the static electricity away from shafting and machines?*

The best way is to "ground" the hangers or some other stationary part by means of a wire fastened to a water, gas or steam pipe, or to a rod driven into damp earth.

83. *Is this method used with dynamos and motors?*

Not generally. The frames of such machines are usually insulated from the ground so as to reduce the danger of the circuits getting "grounded" and so allowing the current to escape or cause damage.

84. *How may the static electricity be removed from dynamos or motors without grounding them?*

The static electricity is of so high pressure that it will travel over paths that are good insulators for the regular current. Such a path is furnished by a moistened string, a pencil mark on a piece of paper, or a can of pure water. Place a can of water on the floor under or near the machine, connect it to a water or gas-pipe by means of a small wire, tie a string to some convenient part of the machine, and

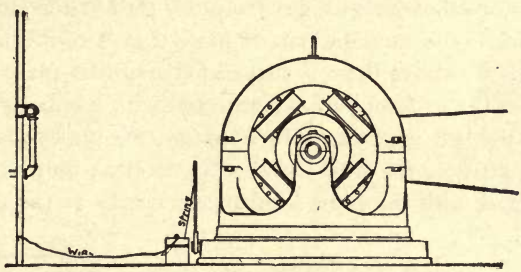


FIG. 84.—REMOVING STATIC ELECTRICITY.

let the end of the string dip into the water. The string will soon become moist enough to carry off the static charge without grounding the machine, Fig. 84. A neater and cleaner way is to make a long mark with a common lead pencil upon a narrow strip of paper; fasten one end of this under the head of a bolt or other convenient place so that one end of the pencil mark touches the machine; a small wire attached to a good ground may be connected with the other end of the pencil mark by means of a washer and screw.

85. *Why do some belts give more electricity than others?*

Rubber belts are usually more highly charged than leather belts because they do not take up moisture and are better insulators.

86. *Can any practical use be made of the electricity from belts?*

It might possibly be used for making ozone, ammonia or nitric acid

from the air. So far as is known, it has not been so used to any great extent. Much can be learned by experimenting with it.

87. *What experiments can be made with static electricity?*

Instructive and interesting experiments may be made with simple apparatus to show attraction and repulsion, conduction, induction, the effect of points, the action of the condenser and the magnetic, heating and physiological effects of electricity.

88. *How can attraction and repulsion be shown by electricity from a belt?*

Hold a doll's head near a belt, and the hair will be attracted to it. Each hair will stand on end as if attracted by the belt, and also stand apart as if repelled by all the other hairs. A similar effect occurs if one places his own head near the belt, being careful, of course, not to get caught by it. A miniature hailstorm or a set of dancing dolls can easily be arranged.

89. *How can dolls be made to dance by electricity?*

Small dolls or other images, cut from dry pith of the elder or cornstalk, are placed on a metallic pan or plate that is connected with the ground. Directly above them is suspended a similar plate that is well insulated from the ground, but is connected with a wire or brush near the belt. If the belt is giving off electricity, the upper plate becomes charged and attracts the pith dolls. As soon as they touch it they become charged with the same kind of electricity as the upper plate,

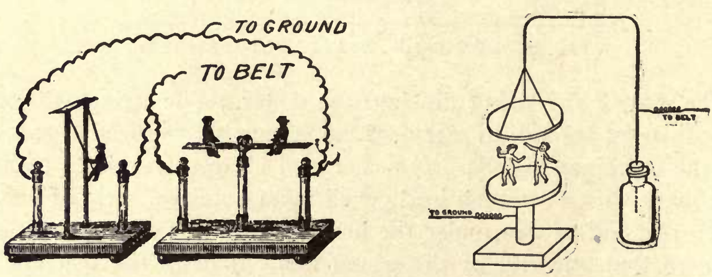


FIG. 89.—ELECTRIC DOLLS.

and are at once repelled (or as seems more likely, are no longer attracted), and fall to the lower plate. Here the charge they received from the upper plate goes off to the ground and they are again attracted by the upper plate. In this way they will dance up and down in a very amusing fashion. Instead of the pith images, bits of straw, grass or paper may be used to make a miniature hailstorm.

90. *Is electrostatic repulsion of any practical importance?*

It is frequently troublesome, as when one undertakes to arrange his hair with a rubber comb on a dry day. The electrification of the hairs causes them apparently to repel one another and refuse to be placed. It has been proposed to throw off disease germs and other dirt by the application of electric charges at high potential. Actual use is made of such action in the automatic drying of the insulators used on lines for transmitting electric power at high potentials, the particles of moisture being actually driven off, so that the insulators become dry even on a misty day. When the electrical pressure is much above 30,000 volts, there is quite an appreciable loss of energy from the charges carried off by the air passing the wires. Electrostatic attraction and repulsion is a source of much trouble in printing offices (see Nos. 74 and 80), and in woolen and cotton mills.

91. *Is electrostatic repulsion used in telegraphy?*

The "siphon recorders" used in connection with submarine cables were based on this phenomenon. The current is too weak to operate any ordinary relay or recording device requiring appreciable

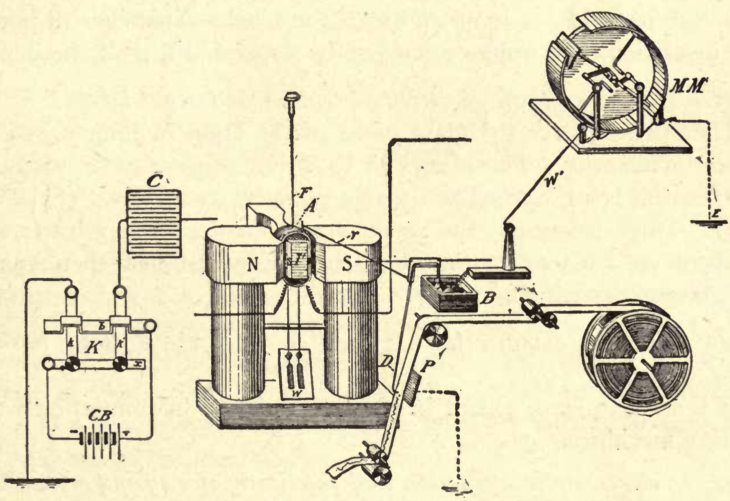


FIG. 91.—SIPHON RECORDER.

force. To secure a record without friction, a fine tube, *D*, connecting with an inkwell, *B,* was attached to the coil of a delicate galvanometer, and also to one terminal of an electrostatic generator, *M,* so that a stream of fine drops of ink was thrown out by repulsion and so records motions of tube past a paper ribbon. A magnet now jolts the siphon.

92. *How is static electricity troublesome in spinning and weaving?*

The fibres become electrified and refuse to lie close together, causing the threads and fabric to become loose. To overcome the trouble, it is common to keep the air moist and to connect the machines with the earth, so as to dissipate or carry off whatever static electricity appears. Somewhat similar trouble is experienced in paper mills.

One of the advantages of the "indirect radiation" system of heating and ventilation is that the humidity of the air is under easy control.

93. *Is static electricity objectionable around electric light plants?*

It is, for it frequently causes the machines to break down and more frequently breaks incandescent lamps. Smaller amounts of static charge often get in electrical measuring instruments and cause the pointer to stick or to give incorrect readings.

94. *How does static electricity break down machines?*

The static electricity is liable to jump from the wires to the ground or to the iron frame of the machine in two places at once. (See No. 132.) The current from the line can follow the path of the spark, although it could not jump and start the spark. This current burns the insulation, and unless immediately stopped will melt the wires.

95. *How does static electricity break incandescent lamps?*

The sparks pierce the glass globe of the lamp in jumping to or from the filament. This allows air to enter and destroy the vacuum, the filament being burned as soon as sufficient air enters. (See No. 125). More frequently the static charge on the globe attracts the filament until it touches the glass, and the intense heat then cracks the glass so that air enters.

96. *Has any commercial use been made of electrostatic attraction?*

It is used to some extent in picking up labels in connection with pasting machines.

97. *Is electrostatic attraction and repulsion of any importance in nature?*

Fog and mist are cleared up in many cases by electrical action. The heavy downfall of large drops of rain immediately following lightning discharges during thunder showers is attributed to similar action. When the air is unevenly electrified, the opposite sides of the small drops of water forming the mist or fog or raincloud are unequally electrified and attract one another, thus forming larger

drops which have less surface than the added surfaces of the individual drops, and consequently fall to the earth. When the air is evenly electrified, the water particles repel one another and remain small, so that the mist or fog continues.

98. *Can electric bells be rung by static electricity?*

Not ordinarily. Telephone bells will sometimes give a single stroke when the line becomes charged by lightning. A special kind of bell known as the "electric chime" may be operated by static electricity from a belt or other source. Two or more bells are suspended at the same height and about a half-inch apart, as indicated by the sketch. Alternate bells are connected with the ground. The remaining bells are well insulated and are connected with a wire or brush that collects electricity from the belt. A light metallic ball is suspended between each pair of bells by means of a silk thread. Each ball will be attracted by the bell that is charged from the belt. After

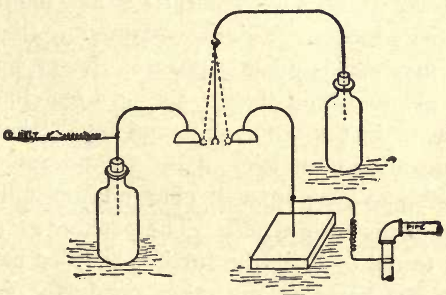


FIG. 98.—ELECTRIC CHIME.

touching that bell, it becomes charged with the same kind of electricity and then is no longer attracted by that bell, but is attracted by the other bell that is grounded. When it strikes the grounded bell, it loses its charge and is again attracted to the first bell. Thus it swings back and forth, ringing both bells continuously. The electric chime was invented by Benjamin Franklin in 1752, to indicate the presence of thunderclouds.

99. *What is meant by the induction of static electricity?*

Hang a tin pail near a belt. Several inches from the first pail hang a second pail that is connected with a third one by a wire, as suggested in the figure. All of the pails should be suspended by dry cotton or silk thread, or should be placed on dry glass jars or bottles, so as to be well insulated from the ground. When the first pail is well charged with electricity from the belt one may get a shock

by touching the third one. The pith ball or leather electroscope will also show that the third one is charged. Since the second and third pails are well insulated from the first and from the belt, and since they are too far apart for the electricity to pass through the

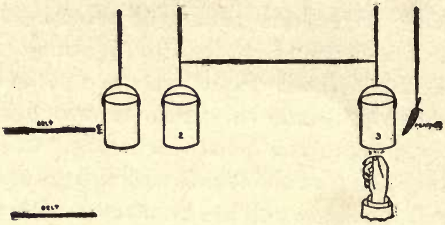


FIG. 99.—ELECTROSTATIC INDUCTION.

air to them (according to the common theory, which does not quite agree with the explanations of the more modern "displacement" theory), the electricity does not seem to get into them by conduction, but by some other process. This is explained by the principle of induction. The first pail is given a positive charge by the belt. According to the old two-fluid theory, the positive charge attracts the negative electricity in the other pails and repels their positive electricity. The negative electricity of the second and third pails gets as close as possible to the positively charged first pail, that is, it goes to the near side of the second pail. The positive gets as far away as possible and is found to be in the further or third pail, and it leaves that also when the hand or any other conductor furnishes a path for it to go still further away.

100. *Is electrostatic induction of much importance?*

The strongest machines for developing static electricity are based on induction. Most of the so-called lightning on electric wires is induced rather than directly drawn from the clouds or lightning. Most of the "cross-talk" and the confusing noises on telephone lines come from electrostatic induction.

101. *Explain how cross-talk on telephone lines is caused by induction?*

The currents used in telephony are alternating; that is, each wire is alternately positive and negative, changing polarity many times each second. The electrostatic induction between neighboring wires is most easily explained by some experiments made by Carty. Suppose that one side of a telephone circuit is near one wire of another circuit, as shown in the figure. At an instant when the disturbing wire is positive, a negative charge is induced in the near side

of the telephone circuit, and the positive charge escapes to the further side. The rearrangement of the charges causes a momentary current as the positive electricity passes to the further conductor, a result being that the current causes noise in the telephones at the

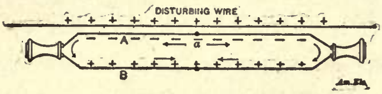


FIG. 101.—ELECTROSTATIC INDUCTION.

ends. Carty found that the noise was not affected if the wires were cut at the points marked *a* and *b,* and also that a telephone would give no noise or evidence of current when connected into the circuit at *a* or *b,* but would when connected between *a* and *b.* These experiments showed that the current causing noise in the telephones at the ends was not caused by electromagnetic induction, since such currents require a completely closed circuit. When the disturbing wire carries an alternating current or fluctuating current, such as used for electric lighting, the potential continually changes, causing corresponding changes in neighboring circuits, and thus causing noises in telephones. If the distributing wire carries a telephone current, such as caused by talking, the induced currents are similar, and the talk is heard in neighboring circuits. It should be remarked that much of the cross-talk is due to leakage caused by imperfect insulation.

102. *How can cross-talk be avoided?*

The part caused by leakage is reduced by improving the insulation. That caused by electrostatic induction may be reduced by increasing the distance between the two circuits. Since the latter is

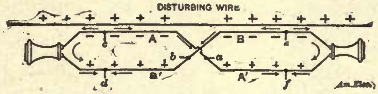


FIG. 103.—TRANSPOSITION TO NEUTRALIZE INDUCTION.

not practicable for many circuits, the wires are transposed at certain intervals, so that the induction in one section balances that in another.

103. *Explain how transposition neutralizes cross-talk.*

Suppose that the disturbed wires are crossed, as suggested in the figure. The negative charges at *A* and *B* have four paths to the opposite wire, and since the resistance of the paths at the crossing is much less than that through the instruments at the ends, most of

the induced current passes through the crossing wires, thus reducing the current and the noise in the telephones. The practice on actual telephone lines is to transpose the wires every quarter or half mile. When a number of circuits are carried on the same poles, it is a matter requiring much experience and judgment to arrange the transpositions so that no circuit shall affect any other.

104. *What effect do points have upon static electricity?*

They scatter it. An interesting experiment is to connect a pointed wire with a spark collector and bring the point near to a candle, as

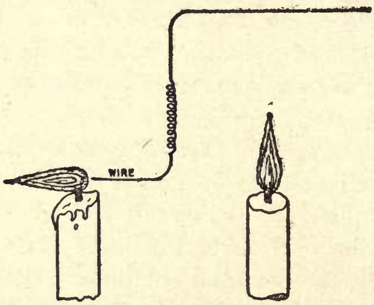


FIG. 104.—ELECTRIC BREEZE.

suggested in the figure. A sort of wind seems to come from the point and blows the flame to one side, or may even extinguish it. A similar thing occurs in the electric whirligig.

105. *What is an electric whirligig?*

It consists of a number of wires radiating from a common center and resting upon a metallic point upon which they may rotate with but little friction. The outer ends of the wires are pointed and are

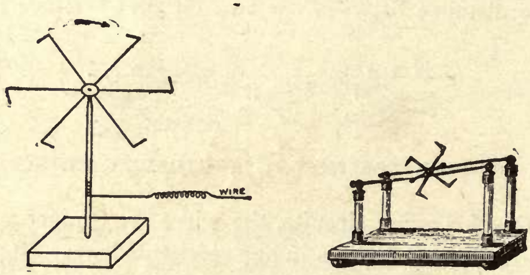


FIG. 105.—ELECTRIC WHIRLIGIGS.

bent backward like the arms of a lawn sprinkler, as in the figure. One may be made by soldering several wires of the same length to a small tin disc, the center of which has been slightly raised by a center

punch, so as to form a socket or bearing. Balance this upon the pointed end of a stiff wire or needle that is well insulated from the ground. Connect the upright wire or needle to the spark collector or to a wire near the belt. If the whirligig is nicely balanced and the standard is well insulated, it will rotate as long as the belt is giving off electricity to the wire.

106. *How is this effect of sharp points explained?*

The reason generally given is that static electricity stays on the outside of conductors or in the insulating medium around them. Where the conductor is small, the charge seems to pile up, its density being inversely proportional to the radius of curvature of the surface. At sharp edges or points, the charge is stronger or denser than at other parts of a conductor. Since electricity of the same kind repels itself, it tends to scatter or discharge at such places. When the insulating material (often called the *dielectric*) is air, oil or other fluid, the dielectric itself is repelled and a current is set up, each particle of air or oil carrying away some of the charge. This is nicely illustrated by the candle and the whirligig. The current of electrified air from the point blows the candle flame. The charge upon the point is also repelled as strongly, and there is a backward pressure upon the wire exactly equal to that of the current of air. If the point is free it will move backward, as shown by the whirligig, which is something like a turbine wheel.

107. *Is any practical use made of the action of points in scattering an electric charge?*

Most forms of lightning arrester use points. Telegraph pro-

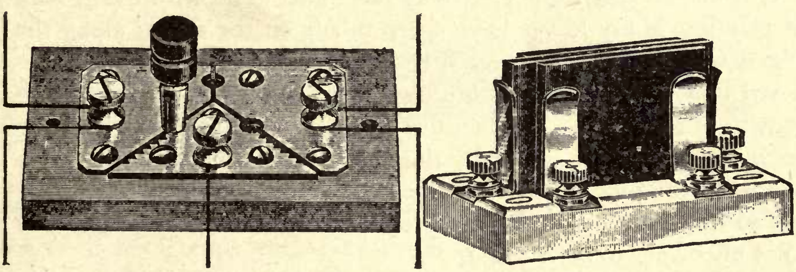


FIG. 107.—LIGHTNING ARRESTERS.

tectors frequently have serrated brass plates, the middle one being grounded. Telephone protectors generally use carbon plates with

mica separators, the rough carbon surfaces presenting a multitude of fine points across which charges are dissipated (see 156). Barbed wires are sometimes strung over power circuits.

108. *Do points collect or attract electricity as well as they scatter it?*

It is a common but erroneous idea that the points on a lightning rod, or an arrester, or belt discharger, actually collect the electricity from the clouds or from the belt. The explanation preferred by scientists is that the charge in the clouds or on the belt *induces* an opposite charge on the pointed metal as explained in answer to No. 99. Suppose the belt is charged positively: electricity is induced in the arrester, the positive part being repelled and going off to the earth; the negative part is attracted to the points and is there scattered, as explained in No. 106. As the negative charge escapes from the points, it unites with and neutralizes the positive charge on the surface of the belt or in the cloud. While, therefore, positive electricity flows away from the lightning or spark arrester, it is the induced positive electricity and not that originally in the cloud or on the belt.

109. *What is the reason why a bundle of fine wires discharges a belt better than a single large wire?*

This is for the same reason as above. The bundle of fine wires presents many sharp points, each of which helps to neutralize the charge. For the same reason also, a piece of tin with a rough edge or with many sharp points is a good spark arrester or discharger.

110. *Does Nature make any use of the electrical properties of sharp points?*

It is known that static electricity has much to do with the growth of plants. Many leaves have sharp points on the spines along the edges, while others are covered with finely pointed hairs. It is believed that these fine points are used in collecting electricity for the growth of the plant. The fact that grass grows but sparingly under cedar and pine trees is largely due to the fact that the many sharp points on the pine needles take nearly all the electricity out of the air, so that little is left for the growth of other vegetation beneath. (See also Nos. 108 and 154.)

111. *What is a Leyden jar?*

This can be understood best from an experiment. Partially fill a bottle with water, carefully dry the outside and place in the bottle a wire long enough to extend several inches above the top. Hold the bottle in the hand, as in the figure, so that the upper end of the wire

is near a belt giving off electricity. After a few seconds touch the wire with the other hand, and you will get a hard shock. The shock will be harder if the wire is held near the belt longer, or if the bottle is larger. This was first discovered by a student in Leyden, and is generally known as the Leyden (pronounced li-den) jar. The more

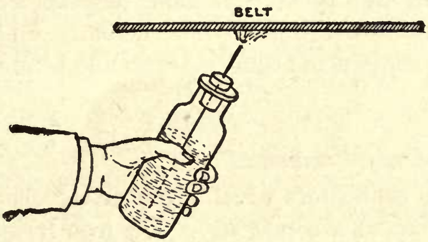


FIG. 111.—LEYDEN JAR.

common form is a glass jar coated on the inside and outside with tin foil up to within a few inches of the top. The glass is carefully kept dry and sometimes is covered with shellac or varnish to keep off moisture which would allow the electricity to creep along the surface from one coating to the other. Connection with the inner coating is made by means of a chain or light wire attached to a knob on the cork top.

112. *What is a condenser?*

A Leyden jar is one form of condenser. The glass jars are so expensive, bulky and easily broken, that another form is generally used when a large capacity is desired. The common form consists

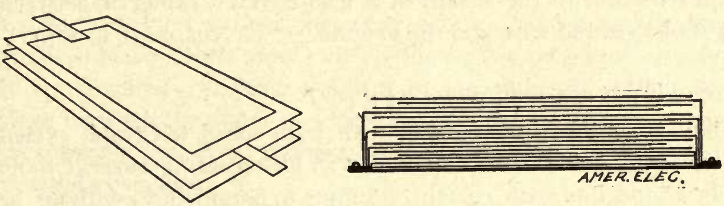


FIG. 112.—CONDENSERS.

of a number of sheets of tin foil separated from each other by sheets of mica or paper soaked in oil or paraffine. The alternate sheets of tin foil are connected together, as indicated in the figure, and are then placed in a wooden box into which melted paraffine is poured so that the whole becomes solid.

113. *Must the surfaces of a condenser be made of tin foil?*

No. Any conductor will do. Tin foil is used because it is cheap

and easily handled. Sheet lead from tea chests, or tin foil from tobacco packing is good for such purpose.

114. *Are ordinary mica or paraffine condensers suitable for experiments with electricity from belts or static machines?*

Electricity of so high pressure is liable to puncture the insulation and ruin condensers of ordinary construction. Only Leyden jars or other specially constructed condensers should be used with charges of high potential.

115. *Are condensers common?*

Yes. Any two conductors which are near together and insulated from each other, act as a condenser. The iron frame of a dynamo or motor and the wire wound upon the fields and armature act as the two surfaces of a condenser, and one may sometimes get a severe shock by touching both at the same time. A long insulated wire buried in the earth or in the water forms a condenser on account of the surface of the wire and the surface of water or earth outside being so large and so close together. This is the principal reason why it is impossible to telephone across the ocean. Much of the "cross-talk" between different lines on the same pole is caused by the different wires acting as surfaces of condensers. (See Nos. 101, 102, 103.) A long lamp cord consisting of two wires or cables side by side has so much capacity that a strong magneto will ring through them, although the insulation resistance between them is millions of ohms. In the same way a strong magneto will ring when connected to the wire and to the sheath of a lead-covered cable, or between a long underground wire and the ground. (See Nos. 1131 to 1135.)

116. *What are condensers used for?*

They are used in connection with high-speed telegraph systems, and to some extent with telephones and alternating-current motors and in connection with certain attempts to obtain light without heat by electric currents of very high frequency. When properly connected and when of suitable capacity, condensers balance the self-induction of long lines or of electro-magnets, so as to enable signals or other rapid variations in the strength or direction of currents to be sent faster with less interference. (This action is rather complicated, and its full explanation requires an extensive knowledge of mathematics and electricity.) Condensers are also used in making accurate scientific measurements. Many experiments with static electricity are much more effective when condensers are used.

117. *Is there a simple and elementary explanation of the action of the condenser?*

Its action may be considered as a result of the mutual attraction between positive and negative electricity. The condenser consists of two large conducting surfaces very close together, such as two or more sheets of tinfoil separated by mica. When the two surfaces are connected with opposite terminals of a source of electricity, such as a battery, a dynamo or a static machine, a positive charge collects on one plate and a negative charge on the other. These charges attract one another so strongly that a large quantity will accumulate. The quantity of electricity held by the condenser depends upon the size of the surfaces, their nearness together, the nature of the insulating material between them and upon the electrical pressure (sometimes called difference of potential) between the terminals of the battery or other source of charge. When the two surfaces are connected by a conductor, the two charges run together, the positive and negative charges neutralizing each other, so that the condenser becomes discharged.

118. *What is the formula for calculating the capacity of a condenser?*

The capacity equals the product of the specific inductive capacity of the dielectric multiplied by the total area of the cross section of the dielectric, divided by a constant factor times the thickness of the dielectric. When the condenser consists of parallel plates of conductor arranged in piles or layers, so that each alternate plate is connected to the same terminal, the cross section of the dielectric equals the total surface (both sides) of all the leaves or plates connected with one terminal. Taking the area in square centimeters and the distance between the plates or leaves in centimeters, and the capacity in microfarads (see Nos. 139 and 202 for definitions of these units), the formula becomes,

$$C = \frac{k\ A}{11{,}310{,}000\ t} \text{ microfarads} = \frac{k\ A}{4\ \pi\ t} \text{ c.g.s. units.}$$

Taking the area in square inches and the thickness in inches,

$$C = \frac{k\ A}{4{,}452{,}000\ t}.$$

119. *Give an example of calculating the capacity of a condenser.*

Suppose the dielectric is paraffined paper having a specific inductive capacity of 1.977 and being 0.03933 in. thick, the area of both

sides of each set of leaves being 205 sq. ft., or 29,520 sq. ins. The formula becomes,

$$C = \frac{1.977 \times 29{,}520}{4{,}452{,}000 \times 0.03933} = 0.3335 \text{ microfarads.}$$

120. *How can the formula be changed to show the area necessary for a desired capacity?*

Using square centimeters area and centimeters thickness,

$$A = \frac{11{,}310{,}000\ C\ t}{k}.$$

Using square inches and inches, it becomes

$$A = \frac{4{,}452{,}000\ C\ t}{k}.$$

121. *What is specific inductive capacity?*

Specific inductive capacity is the quality of a dielectric which enables it to hold an electric charge between two conductors. Air is taken as a standard, its specific inductive capacity being called unity. When two conductors such as two parallel plates are connected to the opposite terminals of a battery or other source of potential difference, the quantity of electricity that flows into or out of the conductors depends upon the nature of the substance between the plates (see No. 117); thus, if two plates were separated a given distance by glass, the combination would constitute a condenser of about three times what the capacity would be with simply air between the plates, hence the specific inductive capacity of glass is about three.

122. *What values does specific inductive capacity have?*

The values vary with the nature of the substance and to some extent with the time during which the plates are connected with the source of charge. Values of common substances have been found as follows:

Vacuum air at 0.001 mm. pressure		about	0.94
" " 5. " "	0.9985	to	0.9994
Hydrogen at 760 " "	0.9997	to	0.9998
Paraffine wax	1.68	to	2.47
India rubber (pure)	2.12	to	2.34
India rubber (vulcanized)	2.69	to	2.94
Resin			2.54
Ebonite	2.21	to	3.15
Shellac	2.74	to	3.73
Gutta percha	2.46	to	4.2
Kerosene	1.92	to	2.26

Glass	3.00	to 9.9
Mica		5.0
Water	75.	to 84.

123. *What is meant by a "residual charge?"*

After a condenser has been discharged and allowed to stand by itself insulated from other conductors, it is frequently found to be charged again, though not to so great an extent as at first. Several successive discharges may thus be obtained, the original charge having apparently soaked into the dielectric. For the same reason, the amount of charge a condenser takes depends upon the length of time given for charging. Mica and air do not soak up the charge.

124. *Can any interesting experiments be made with a condenser, or Leyden jar?*

One can get or give shocks by them; make a person see stars; kill flies or rats; pierce holes in cardboard or even in glass; make lightning and thunder on a small scale; set fire to gas or alcohol; get pretty luminous effects. Other experiments will suggest themselves to the observant student.

125. *How can a condenser be used to give a shock?*

One method was suggested in No. 103. A favorite joke in electric light stations is to charge, or "load," an incandescent lamp by holding it near a belt, and then to hand it to some unsuspecting person; or if the room is very dry leave it in some convenient place for curious persons to examine.

126. *Is it possible to kill rats or flies by the spark from a belt?*

They can be given shocks that will greatly surprise, and sometimes stun or even kill them. Arrange two strips of metal side by side and well insulated from one another, as suggested in the figure. Dry wood will insulate well enough. Connect one strip to a spark col-

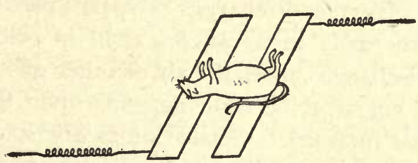


FIG. 126.—ELECTROCUTION.

lector, such as a brush or wire near the belt, and connect the other end with the water pipe or other good ground. When any animal crosses from one to the other in such a way as to touch both metal strips at once he will regret it. A similar plan may be arranged to

prevent people from committing nuisance. In a similar way butchers and candy merchants have reminded meddlesome persons against handling their meat or other wares.

127. *How can one see stars by electricity?*

A drinking glass with metal case such as used at soda fountains makes a condenser that may be loaded easily, as suggested in No. 111, the liquid and the metallic holder being the two surfaces. After the cup is charged (not too strongly for fear of injuring the victim), hand it to a friend to drink. He will see stars and will endeavor to share the sensation with the perpetrator of the joke. One can also see stars by the help of an incandescent lamp. Charge a lamp feebly by holding the bulb in the hand and bringing the lamp base near a belt for a short time, being careful not to charge it too strongly; then touch the lamp base to the forehead. One will seem to see a flash of light, although the eyes are tightly closed. The electricity passing between the forehead and hands affects the optic nerve in about the same way that light affects it.

128. *How can luminous effects be produced by a condenser or by static electricity?*

An incandescent lamp—one with a broken filament is as good as any—will become luminous if held in the hand and brought near the belt. Pretty effects are obtained by moving the fingers to different parts of the bulb. For some time after the bulb has been charged, it may be made to glow by simply rubbing with the hand. These effects are much prettier in a dark room. Sometimes when the lamp is highly charged, sparks will pass along the surface of the glass or will seem to jump through it, and will give one quite a hard shock.

129. *What is a Geisler tube?*

This is a glass tube containing two platinum wire terminals passing through the glass and having the air exhausted so as to leave a partial vacuum. Electric discharges or sparks pass between the two wires much more easily in a vacuum than in ordinary air. The passage of the discharge causes the air or other gas to become dimly luminous. The color of the light depends upon the kind of glass and upon the gas inclosed. Geisler tubes are sometimes made in beautiful designs. An incandescent lamp is the most common form of Geisler tube.

130. *Can Geisler tubes be used for lighting purposes?*

Until recently the Geisler tube has been principally an interesting scientific toy, but for several years past a number of investigators have been trying to put it into shape for lighting purposes. The

Geisler tube is the most efficient source of artificial light that is known; that is, a larger proportion of the total energy delivered to it is changed into light than by any other known means. But the light from such tubes is always very small, and hence is not suitable for general illumination. Tesla, Moore and others have done much work along this line, and it is one of the most promising fields of electrical research.

131. *How can lightning and thunder be produced artificially?*

The crackling sound heard when a spark passes is really thunder on a small scale, and the spark is miniature lightning. The noise is caused by the sudden heating and cooling of the air by the spark. The larger the condenser and the higher the potential, the louder will be the sound.

132. *How can the spark be made to pierce holes in cardboard or glass?*

Paper or cardboard can be pierced by connecting the two terminals of a charged condenser to two points directly opposite each other and separated only by the paper. In passing between the two points, the sparks make small holes in the paper or cardboard. By having a condenser sufficiently large and charged to a very high potential, such as may be obtained by a large static machine, one may pierce holes through glass. (See Nos. 94 and 95.) The apparatus in some of the universities will pierce glass $\frac{1}{4}$ in. thick. By examining carefully the appearance of the hole through paper, cardboard or glass to discover the direction in which the spark passed, one sees that the spark seemed to go in both directions or to start in the middle. The evidence of extended experiments with more complicated apparatus confirms the belief that the spark really consists of a number of sparks going first in one direction and then in the other; in other words, the discharge of a condenser is often oscillatory, the spark passing back and forth like the swinging of a pendulum. Careful study of experiments along this line has led scientists to believe that lightning discharges are generally oscillatory, and the most efficient lightning arresters are made upon that idea. Further reasoning from this point strengthens the theory and belief that electricity itself is a vibratory motion, and almost if not quite identical with light.

133. *How can alcohol be set afire by a spark?*

Put the alcohol in a dish in which a wire or other conductor is placed, so that the end is at or just below the surface of the alcohol. Connect the further end of the wire to one terminal of the charged

condenser and bring the other terminal near, so that a spark will pass to the point in the alcohol. The spark at the surface of the alcohol and air will set it afire. Cigar lighters are sometimes made upon this principle, the spark being produced by a frictional machine or by an induction coil.

134. *How can gas be lighted by a condenser?*

This is practically the same thing as described in Nos. 43 and 54. Connect one terminal of the condenser to the gas-pipe by means of a wire, chain or wet string; turn on the gas and bring the other terminal of the condenser near the gas jet, so that the spark will pass through the stream of gas. If you do not mind a shock, hold one terminal of the condenser in one hand, turn on the gas and bring the other condenser terminal near the gas jet while still holding the gas cock. The discharge will then pass through your arms.

135. *Can static electricity be measured?*

Both the quantity and the pressure of static electricity can be measured by suitable instruments.

136. *What units are used in measuring static electricity?*

There are two systems of units, the electrostatic and the electromagnetic. The electrostatic units are not often used, except in purely theoretical and mathematical work. The electromagnetic units used in connection with static electricity are the coulomb, the volt and the farad or microfarad. (See also No. 224.)

137. *What is a coulomb?*

The coulomb is the electromagnetic unit of quantity of electricity. It is 3,000,000,000 times the electrostatic unit of quantity, which is the quantity which would repel an equal quantity at a distance of one cm with a force of 1 dyne. The coulomb is the quantity of electricity represented by a current of 1 ampere during one second of time. It is the quantity of electricity in a condenser of one farad capacity when charged at a pressure of 1 volt. The unit is named after Charles A. Coulomb, a celebrated physicist, who lived from 1736 to 1806. (See also No. 229.)

138. *What is a volt?*

The volt is the unit of pressure or electromotive force. It is the pressure required to force one coulomb of electricity into a condenser of one farad capacity. A "Clark standard cell" has an electromotive force of 1.434 volts. The pressure of a sal ammoniac or Leclanche cell of battery is about 1.4 volts; that of a gravity or "Crowfoot" cell is about 1.1 volts. The volt is the electromotive force

set up in a conductor that "cuts" or crosses magnetic lines of force at the rate of 100,000,000 per second, or a coil in which the number of magnetic lines inclosed changes at the same rate. The volt is named after Alessandro Volta, an Italian physicist, who lived from 1745 to 1827. (See also Nos. 228 and 235.)

139. *What is a microfarad?*

It is the practical unit of capacity, being one millionth part of the farad. The standards actually used consist of sheets of tin foil separated by thin mica, the layers or sheets being connected alternately, as indicated in Fig. 112. The farad is named after Michael Faraday, a celebrated British physicist of the early part of the nineteenth century, 1791 to 1867. (See also No. 230.)

140. *How can a quantity of static electricity be measured?*

It can not easily be measured directly. The most common method is to measure the current it will cause for a short time. This is done by the use of a ballistic galvanometer. The quantity can be calculated from the capacity and pressure, as the number of coulombs equals the product of the number of farads by the number of volts.

141. *What is a ballistic galvanometer?*

The ballistic galvanometer has a comparatively heavy moving part that swings so slowly that the transient current from the discharge of a condenser or similar source can practically all pass through the coil before the moving part has moved sensibly away from the zero point. (See No. 832 for further description of galvanometer.) The throw of the needle, that is, the amount it is deflected at the first swing, is proportional to the quantity of electricity that passes through the coil.

142. *How can the pressure of static electricity be measured?*

The pressure or potential can be accurately measured by various forms of electrometers. Electrometers are based upon the simple principle that there is an attraction between bodies at different potentials, or, as sometimes stated (see No. 25), that bodies similarly charged repel each other, while bodies oppositely charged attract. The commercial forms are known as "electrostatic voltmeters."

143. *Describe the electrostatic voltmeter.*

The simple form is illustrated in the figure. It consists of two butterfly shaped sheets of brass parallel to each other and metallically connected together and to one binding post, but carefully insulated from the rest of the instrument. Midway between them is the "needle," a light and thin strip of aluminum pivoted on knife

edges and carrying a light pointer at the upper end. The lower half is slightly heavier than the upper half, so that the pointer stands at zero. The needle is carefully insulated from the stationary plates and is connected with the other binding post. When the two binding posts are connected with the terminals of a dynamo or any other points having a considerable difference of potential, the plates and

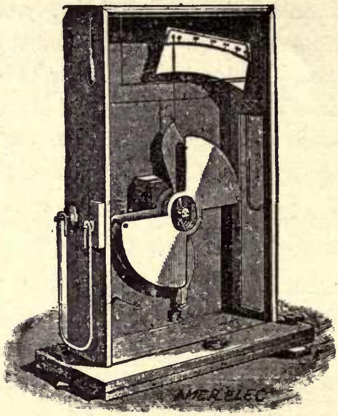


FIG. 143.—ELECTROSTATIC VOLTMETER.

the needle are charged to corresponding differences of potential and attract one another. The needle, therefore, moves so as to get closer to the plates, or, what is the same thing, swings on the knife edges so that a larger part of the needles is between the stationary plates. Since the lower half of the needle is heavier than the upper, any motion of the needle means lifting a weight, so that the electrostatic attraction is balanced by gravity. The amount of the motion of the needle, therefore, measures the difference of potential between the needle and the stationary plates, that is, between the terminals of the instrument. The form of voltmeter shown in the figure is suitable for differences of potential between 200 and 20,000 volts. Another style is made for potentials up to 100,000 volts. (See also Nos. 801, 802 and 803.)

144. *Can electrostatic voltmeters be made to measure less than 200 volts?*

The multicellular form is used for pressures between 40 and 1600 volts. The figure shows one style of Thomson or Kelvin multicellular voltmeter. The moving plates are fastened to a stiff vertical wire which is suspended by a fine wire that becomes twisted

slightly when the moving part is drawn in between the stationary plates. The torsion of the suspension wire is the controlling force

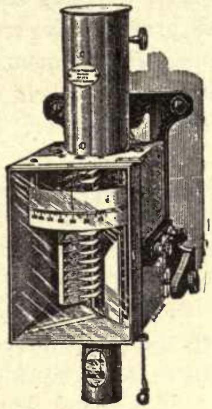


FIG. 144.—MULTICELLULAR VOLTMETER.

in this instrument. A piece of metal hangs in a dish of glycerine or oil below to make the instrument more dead-beat.

145. *Is not the electrometer sometimes made for measuring small differences of potential?*

The "quadrant electrometer," designed by Lord Kelvin, is sometimes made so sensitive as to measure pressures as low as 1/1000 volt. It is only useful for laboratory work in the hands of skilful observers.

146. *What are the advantages of electrostatic instruments?*

They are suitable for measuring either direct or alternating pressures (except that the quadrant electrometer is not so sensitive for very small alternating pressures), since the attraction depends upon the difference of potential between the plates and is independent of their relative polarity. Another advantage is that it takes no perceptible current or energy, and so does not become heated in use. It is especially valuable in cases where there is no current or where such is not desirable.

147. *Can an electrometer be used to measure different kinds of electricity?*

The electrometer will measure differences of potential, no matter from what source. It shows that the electricity obtained by friction is the same as that obtained from chemical action in batteries or by induction in dynamo machines. The electricity from friction is

small in quantity, but of high pressure or electromotive force; while that from batteries is of comparatively low pressure, but may be of considerable quantity. By connecting several thousand battery cells in series, one may obtain precisely the same effects as from belts or friction. Also by proper arrangements, one can obtain from a source of static electricity, such as a belt, the same effects as are produced by a small current from a battery. (See Nos. 4 and 158.)

148. *Is the air itself electrified?*

It seems so. Probably the electricity in clear air is carried by the invisible particles of moisture always present. The atmospheric electricity undoubtedly has much to do with the growth of plants and animals. The sharp spines on the edges of leaves and the fine hair on most plants seem to be partly for the purpose of collecting electricity from the air. It is found that under shade trees the air is less electrified than away from them, and many eminent scientists believe that is why grass does not grow so well under trees as in open fields. They think the shade is not the only reason, and perhaps not the principal one. Probably the reason why nothing grows well under pine or cedar trees is that the many sharp points of the pine needles deprive the surrounding air of its electricity. It is found that the evaporation of water from animals and plants is much faster in electrified air.

149. *What causes the lightning?*

The clouds are more or less charged with electricity. When the difference of potential between two clouds or between a cloud and the earth becomes very great, the air can not stand the strain and "breaks down," allowing a discharge to occur between the two. Much study has been given to this subject and much remains to be learned. Several theories have been proposed to explain the electrification of the air. When water evaporates, the particles of moisture are found to be electrified. When these particles collect and form clouds their charges unite, each drop of water containing the charges of the particles composing it. As the drops get larger and larger, their potential also rises and the whole cloud is electrified more and more strongly. It is often noticed during a thunder shower that the raindrops are larger just after a lightning flash overhead. The peculiar yellowish color in the clouds during a thunder storm is probably caused by small discharges between drops or between small clouds in the larger cloud mass.

150. *What causes the "heat lightning" often seen summer evenings when there is no thunder storm near?*

This is the reflection from lightning in distant storms. In one investigation it was found the "heat lightning" was reflected from a storm over 100 miles away.

151. *Does the aurora have anything to do with electricity?*

Auroral displays, or "Northern Lights," are generally connected with "magnetic storms," which affect compass needles and long telephone and telegraph wires. The exact cause is not certain, but it is believed to be "electrical discharges in the upper air, in consequence of the differing electrical conditions between the cold air of the polar regions and the warmer streams of air in vapor raised from the level of the ocean in tropical regions by the heat of the sun." The auroral displays seem to be intimately associated with sunspots.

152. *What connection is there between the aurora and magnetic storms?*

The two generally occur together. The magnetic disturbances are probably caused by currents in the earth, set up by induction from the electrical discharges of the aurora. Such currents sometimes greatly interfere with the operation of long telephone and telegraph lines.

153. *What causes the humming of telegraph and telephone wires?*

This is principally due to mechanical vibration caused by the wind, these vibrations often travelling along the wires for miles.

154. *Has atmospheric electricity ever been used, or is it likely to be?*

The quiet effects of the electricity are doubtless of great value in agriculture. The remarkably rapid growth of vegetation during the short summers in Finland and other northern countries is believed to be due largely to the great amount of atmospheric electricity present. (See also Nos. 110 and 148). The lightning apparently causes the formation of more or less nitric acid and ammonia found in the air after thunder showers. Many interesting experiments have been made. Probably the largest commercial enterprise yet developed from atmospheric electricity is the manufacture of lightning rods and lightning arresters.

155. *Are lightning rods of any value except to the agent?*

When properly put up they are undoubtedly a source of much protection. The conductor should be made of galvanized iron rather

than of copper: flat strip is some better than round or fancy star shape. Sharp bends and corners in the conductor should be avoided. The conductor should be carried to all high points of a building, should be insulated from the building, and should be well connected with good, deep, *wet* earth, independent of gas or water pipes. All metal work on the outside of the building, such as water pipes, iron cresting, etc., should be connected together and to the earth, but *not* to the lightning conductor. "The cheapest way of protecting an ordinary house is to run common galvanized iron telegraph wire up all the corners, along all the ridges and eaves and over all the chimneys; taking them down to the earth in several places to damp ground, and at each place burying a load of broken coke or charcoal to hold moisture." Lightning rods should not be left on buildings after the connection with the earth is broken or removed. It is found that the network of wires used in cities for telephone, telegraph and other purposes is a great protection. Cases of buildings and trees being struck by lightning are much less frequent in such cities than in the country.

156. *What is the principle of the lightning arresters used for protecting electrical apparatus?*

Many of these depend upon the fact that lightning discharges will jump across air spaces that are good insulators for the regular working current, while they find difficulty in passing through circuits

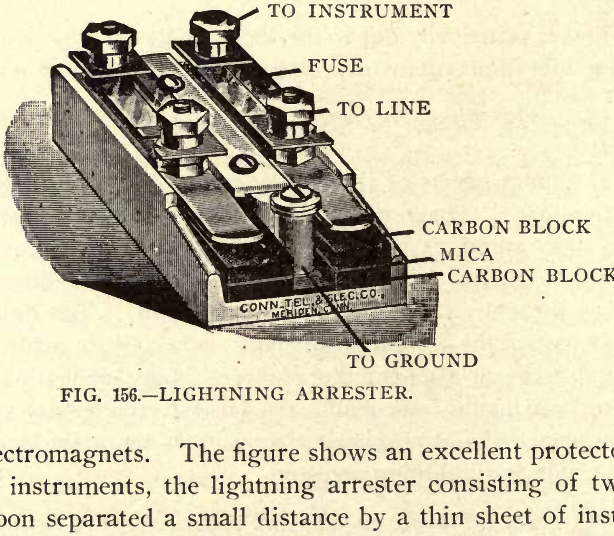


FIG. 156.—LIGHTNING ARRESTER.

containing electromagnets. The figure shows an excellent protector for telephone instruments, the lightning arrester consisting of two blocks of carbon separated a small distance by a thin sheet of insulating mica, which is perforated with one or more holes; a high potential charge on the line will jump through the hole in the mica

from the carbon on the line side to the lower carbon, which is connected with the ground; the fuses protect the instruments against foreign currents which might damage, although not of sufficiently high potential to jump to earth; sometimes the connections are reversed so that the fuse is between the line and the earth. The complete theory of lightning arresters, is complicated, and cannot be understood without a broad knowledge of electricity. The aim of the arresters is to provide a path for lightning to get to the earth without going through the instruments or other apparatus. Arresters for electric light or power circuit also require some arrangement to prevent the regular working current from following the lightning.

157. *Does lightning often strike electric light or telephone lines?*
Lines are very rarely struck with actual lightning from the clouds in the way that trees are struck. The lines become charged to a high potential by induction from lightning flashes or from the passing of clouds that are highly charged. The induction from the presence of clouds is similar to that described in No. 99.

158. *What is the difference between static electricity and current?*
One is electricity at rest, the other is electricity in motion. When static electricity is properly handled, it will produce most of the results obtained from currents. If the two surfaces of a charged condenser are connected by wire or other conductor, the charge on one surface passes around to the other and unites with or neutralize it. While this discharge is taking place, an electric current is moving through the wire from the positive side of the condenser to the negative side. This current lasts only a short time, usually only a small part of a second, but while it lasts it heats the wire and gives magnetic effects much the same as an ordinary current. Likewise the effects of static electricity may be produced by current electricity if the voltage is very high, several thousand volts. Even with low voltage, some static effects can be produced, as illustrated in answers 94 to 98.

CHAPTER II.

UNITS.

200. *What is the "metric" or "C. G. S." system of units?*

This is a system worked out in Paris about a hundred years ago and gradually adopted by scientists in all parts of the world. It is legalized, but not made compulsory, by Congress. The name "C. G. S." is an abbreviation of "centimeter-gram-second," indicating the principal units of the system.

201. *Why do so many electrical engineers use the metric system?*

Because its units are regularly related on the decimal system, so that it is easy to pass from one unit to another without so many and tedious calculations, as are necessary in the English system. The electrical units are derived from the "C. G. S." units and for the sake of uniformity, as well as convenience, electrical engineers use the same system as other scientists. On account of the common use of the English pound and inch in the shops, it is frequently necessary to use the English units in giving dimensions, so that both systems are used together.

202. *What is the centimeter?*

The centimeter is the unit of length and was intended to be the one thousand-millionth part of the distance from the equator to the pole of the earth. Practically, it is the one hundredth part of the distance between two parallel lines ruled on a bar of platinum which is carefully preserved in the Archives of Paris. The word "meter" is derived from Greek, Latin and French words meaning "measure."

203. *What are the other units of length used in the metric system?*

The millimeter is one-tenth part of the centimeter. The meter is 100 cm. The kilometer is 1000 meters.

204. *What is the English equivalent of the centimeter?*

The centimeter equals 0.393704 inch, or 1 in. equals about 2.5 cm. A meter is about 39.4 ins. A kilometer is about $\frac{5}{8}$ mile. A square centimeter is 0.155 sq. ins., and a square inch equals 6.452 sq. cm.

205. *What is the gram?*

The gram, or gramme (from the Greek and Latin *gramma,* "a small weight"), is the unit of mass and also of weight, that is, of the force with which the mass is attracted by the earth. It is the mass or weight of a cubic centimeter of water at 4 deg. C., or 39.2 deg. F., the temperature at which its density is greatest.

206. *What is the English equivalent of the gram?*

The gram equals 15.432 gr., or 0.03527 oz., or 0.002204 lb.,

AMPERE

avoirdupois. The kilogram (1000 grams) equals about 2.2 lbs. One ounce avoirdupois equals 28.35 grams. One avoirdupois pound equals 0.4536 kilogram of 453.6 grams.

207. *What is the second?*

The second is the unit of time, and is the same in the metric and English systems. It is the time of a single swing of a pendulum 0.99355 meter long at sea level, 45 deg. latitude, and is 1-86400 of the mean time from noon to noon, that is, of a mean solar day.

208. *What is the C. G. S. unit of force?*

The dyne (derived from a Greek word meaning "force") is the metric or C. G. S. unit of force. It is the force which, when acting for one second on a mass of one gram, gives it a velocity of 1 cm. per second. The earth attracts every particle at its surface with a force of 978 to 983 dynes for each gram of mass.

209. *What is the C. G. S. unit of work?*

The unit of work and of energy is the erg. It is the work done by

VOLTA

a force of one dyne acting through a distance of 1 cm., or, it is the work done in pushing a body through a distance of 1 cm. against a force of 1 dyne. The work of lifting 1 gram 1 cm. is about 980 ergs. (Erg is derived from the Greek word *ergon,* meaning "work.")

210. *What is the practical unit of work?*

There are two units in each system, the joule and the kilogram-meter in the metric system, and the foot-pound and horse-power-hour in the English. The joule equals 10,000,000 ergs. The kilogram-meter equals about 98,050,000 ergs, depending upon the strength of

gravity. The English unit is the foot-pound, which is the work done in lifting 1 lb. 1 ft. against the force of gravity. The horse-power-hour is a larger unit, equal to the work of lifting 1,980,000 ft.-lbs. The foot-pound unit equals about 13,560,000 ergs, or 0.138 kilogram-meters. The kilogram-meter equals 7.233 ft.-lbs.

211. *What is the difference between work and energy?*

Energy may be considered as a cause of which work is the result Both are measured in the same units, the erg, joule or the kilogram-

OHM

meter in the metric system, or the foot-pound in the English system.

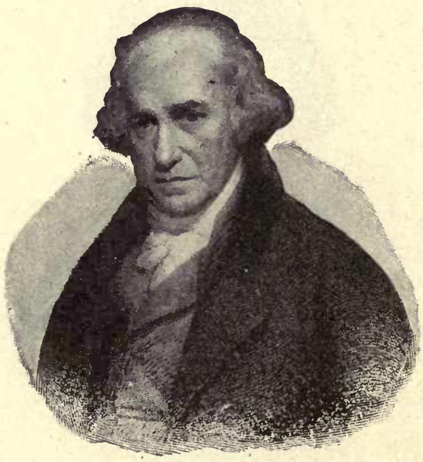
212. *What is the difference between work and power?*

Power is the rate of doing work. To raise 55 lbs. 10 ft. would require 550 ft.-lbs. of energy. To do this in one second would require 550 ft-lb.-seconds, or 1 hp. To raise the same weight an equal distance in one hour, or 3600 seconds, would require only 1-3600 hp. The same work is done in the two cases, but the power is different, because more time is taken in the second case.

213. *What is the metric unit of power?*

The unit is the watt, which equals one joule per second. A larger

unit is often used, the kilowatt, which equals 1000 watts. The number of watts equals the product of amperes by volts, or the product of resistance by the current squared. The joule was named after James Prescott Joule (1818 to 1889), an English physicist who did much to verify the law of conservation of energy. The watt was named after James Watt (1736 to 1819), who greatly improved the steam engine, being practically the inventor of the modern engine. (See Nos. 231, 232.)



WATT

214. *What is the English unit of power?*

The English unit is the foot-pound-per-second, or foot-pound-per-minute, and equals the power required to raise a weight of 1 avoirdupois lb. 1 ft. per second, or per minute, against the attraction of gravity. The watt equals 0.737 ft.-lbs. per second, or 44.239 ft.-lbs. per minute. The horse-power is frequently used as a unit, being the power required to do the work at the rate of 550 ft.-lbs. per second, or 33,000 ft.-lbs. per minute.

215. *How much power is required to raise a weight of 20,000 pounds a distance of 20 feet?*

It depends upon the time in which it is to be done. A small boy could raise it with a differential pulley of sufficient multiplying power; a team of horses could raise it in a much shorter time. The power increases as the time allowed decreases.

216. *What is the relation between watts and horse-power?*

The horse-power equals practically 746 watts, or more exactly, 745.941 watts.

COULOMB

217. *Is the horse-power equal to the power of one horse?*

It was originally intended to be the power that could be continuously exerted by a good strong horse, just as the foot was taken as the average length of men's feet. As engineering and commerce became of more importance, it became necessary to have more definite standards, and so the foot and the pound came to be copies of standards kept by various governments.

218. *What is a kilowatt-hour?*

This is the unit commonly used in measuring electrical energy.

It is the energy represented by 1 kw. operating for one hour. For example, 50 kw-hours might mean 50 kw. for one hour, or 1 kw. for fifty hours, or 200 kw. for a quarter-hour. (See No. 210.)

219. *What is the difference between a kilowatt-hour and a horse-power-hour?*

The same ratio exists as between the kilowatt and the horse-power. The horse-power represents 746 watts, therefore, 1 hp-hour represents 746 watt-hours, or 0.746 kw.hour.

JOULE

220. *What is the relation between heat and work?*

The English unit of heat is that quantity required to raise the temperature of one pound of water one degree Fahrenheit at the temperature of greatest density, 39.1 deg. Fahr. This is called the "British Thermal Unit," and is usually referred to as "B. T. U." or as "B. t. u." Prof. H. A. Rowland experimentally determined its value, which is equal to 778.104 foot pounds, often taken as 778.

221. *What is the metric unit of heat?*

The calorie is the work required to raise the temperature of one gram of water one degree centigrade at or near the temperature of

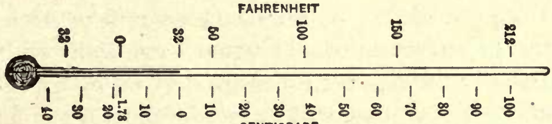
4 deg. cent. It equals 41,861,700 ergs, or 4.2 joules or volt-ampere-seconds or watt-seconds. It is sometimes called the gram-calorie or lesser calorie, to distinguish it from the greater calorie which is 1000 times larger.

222. *What is the difference between Fahrenheit and Centigrade thermometers?*

Fahrenheit (a German physicist living from 1686 to 1736) took what he supposed was the lowest possible degree of cold and called it

FARADAY

zero. He then divided the range between the freezing and boiling points of water at ordinary atmospheric pressure into 180 equal parts



and continued the scale to the zero point, which made the freezing point come at 32 degs. The Centigrade scale was worked out in

1741 by Prof. Anders Celsius, of Upsala, Sweden, who divided the range between freezing and boiling into one hundred equal parts. The Centigrade thermometer is commonly used in scientific work, while the Fahrenheit scale is more often used by engineers who are accustomed to the English scales and units.

223. *How can degrees be changed from one scale to the other?*

To reduce degrees Fahrenheit to degrees Centigrade, subtract 32 and multiply by 5/9. To reduce degrees Centigrade to degrees Fahrenheit, multiply by 9/5 and add 32 degs.

HENRY

224. *What systems of electrical units are in use?*

The electrostatic and the electromagnetic units. The former system is derived from considering as a unit the amount of static electricity that will repel or attract an equal amount 1 cm. away with a force of 1 dyne. The electromagnetic units are derived by considering as a unit magnetic pole one that will attract or repel a similar pole at a distance of 1 cm. with a force of 1 dyne. The "absolute" or "C. G. S." electromagnetic unit of quantity of electricity is 30,000,000,000 times the electrostatic unit of quantity, this factor being closely equal

to the velocity of light in centimeters per second. Ratios between other corresponding units are derived from this. For most purposes the electromagnetic units are used, or, more commonly, the practical units derived from them. (See also Nos. 136 and 246.)

225. *What is meant by the international electrical units?*

These are units recommended by the International Congress of Electricians held in Chicago during the World's Fair of 1893, and later adopted by various governments, the United States Congress

MAXWELL

approving and adopting them in June, 1894. These units include the ohm, ampere, volt, coulomb, farad, joule, watt and henry.

226. *What is the international ohm?*

"The unit of resistance shall be what is known as the international ohm, which is substantially equal to one thousand million units of resistance of the centimeter-gram-second system of electromagnetic units, and is represented by the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice fourteen and four thousand five hundred and twenty-one ten-

thousandths grams in mass, of a constant cross sectional area, and of the length of one hundred and six and three-tenths centimeters." (See also Nos. 234, 237, 315, 318.) This unit is named after George Simon Ohm, a German mathematician, who lived from 1789 to 1854.

227. *What is the international ampere?*

"The unit of current shall be what is known as the international ampere, which is one-tenth of the unit of current of the centimeter-gram-second system of electromagnetic units, and is the practical

GAUSS

equivalent of the unvarying current, which, when passed through a solution of nitrate of silver in water, in accordance with standard specifications, deposits silver at the rate of one thousand one hundred and eighteen millionths of a gram per second." (See also Nos. 236, 241, 317.) This unit is named after Andre Marie Ampere, a French physicist who lived from 1775 to 1836.

228. *What is the international volt?*

"The unit of electromotive force shall be what is known as the international volt, which is the electromotive force that, steadily ap-

plied to a conductor whose resistance is one international ohm, will produce a current of an international ampere, and is practically equivalent to one thousand fourteen hundred and thirty-fourths, $\left(\frac{1000}{1434}\right)$, of the electromotive force between the poles or electrodes of the voltaic cell known as Clark's cell, at a temperature of 15 degs. C., and prepared in the manner described in the standard specifications." (See also Nos. 138, 235.) The volt is named after Alessandro Volta, an Italian physicist who lived from 1745 to 1827.

229. *What is the international coulomb?*

"The unit of quantity shall be what is known as the international coulomb, which is the quantity of electricity transferred by a current of one international ampere in one second." (See also No. 137.) This unit is named after Charles A. Coulomb, a celebrated French mathematical physicist, who lived from 1736 to 1806.

230. *What is the international farad?*

"The unit of capacity shall be what is known as the international farad, which is the capacity of a condenser charged to a potential of one international volt by one international coulomb of electricity." (See also No. 132.) This unit is named after Michael Faraday, a celebrated English physicist, who lived from 1791 to 1867.

231. *What is the international joule?*

"This unit work shall be the joule, which is equal to 10,000,000 units of work in the centimeter-gram-second system, and which is practically equivalent to the energy expended in one second by one international ampere in an international ohm." (See also No. 213.)

232. *What is the international watt?*

"The unit of power shall be the watt, which is equal to 10,000,000 units of power in the centimeter-gram-second system, and which is practically equivalent to the work done at the rate of one joule per second." (See No. 213.)

233. *What is an international henry?*

"The unit of induction shall be the henry, which is the induction in a circuit when the electromotive force induced in this circuit is one international volt, while the inducing current varies at the rate of 1 ampere per second." This unit was named after Joseph Henry, an American physicist, who discovered many of the laws of electromagnetic induction.

234. *What is meant by a legal ohm?*

The "legal ohm" was the temporary standard of resistance adopted by a committee of the International Congress of Electricians, held at

the Paris Exhibition in 1881. This was the standard from 1882 until 1894, and is equal to $\frac{1060}{1063}$ international ohms. (See Nos. 226, 234.)

235. *What is meant by a legal volt?*

The "legal volt" was adopted by the same committee and bears a similar ratio to the international volt. (See also Nos. 138, 228.)

236. *What is the legal ampere?*

The "legal ampere" had the same value as the international ampere. (See No. 227.)

237. *What is meant by the "B. A. unit?"*

The British Association made a determination of the value of the ohm in 1863 and constructed several copies of their standard. This value was equal to 0.9863 international or true ohms. (See No. 226.)

238. *What is meant by "Siemens' units?"*

The "Siemens' unit" of resistance was originally proposed by Werner Siemens (a German electrician living from 1816 to 1892), being the resistance of a column of mercury 1 m. long and 1 sq. mm. in section. This was in use for a number of years in Germany. It equals 0.9408 international ohms. (See No. 224.)

239. *What is a megohm?*

A megohm is 1,000,000 ohms. It is a unit often used in measuring very high resistances, such as insulation. For instance, when a wire is guaranteed to have an insulation resistance of not less than 300 megohms per mile, it means that the resistance between the wire and the earth or the lead covering is not less than 300,000,000 ohms for a length of 1 mile, and proportionally greater for shorter lengths.

240. *What is a microhm?*

A microhm is a unit sometimes used, being equal to one millionth part of an ohm. For example, the specific resistance of substances is usually given in microhms, being the resistance in millionths of an ohm between the parallel faces of a cube 1 cm. in each direction.

241. *What is a "maxwell?"*

The maxwell is one line of force, the practical and the c.g.s. unit of magnetic flux, which when uniformly distributed over a cross section of 1 sq. cm. produces a tension of $\frac{1}{8\pi}$ dynes. The Paris Congress of 1900 named it after James Clerk Maxwell (1831–1879), founder of the electromagnetic theory of light.

242. *What is a "gauss?"*

The name "gauss" was adopted by the Paris International Electrical Congress of 1900 for the practical unit of magnetic intensity, being one maxwell, or one line of force per square centimeter. The unit is named after Carl Frederick Gauss (1777-1855), who invented the declination compass.

243. *What is a "line of force?"*

A line of force is the expression used to indicate either the direction or the strength of a magnetic force. The "unit magnet pole" is a magnetic pole of such strength that it will repel an equal pole with a force of 1 dyne when at a distance of 1 cm. apart. Any magnetic field in which such a unit pole is attracted or repelled with a force of 1 dyne is said to have a strength of "one line of force per square centimeter."

244. *How strong is the earth's magnetic field?*

It varies in different places and at different times. In New York City, the total magnetic field due to the earth's magnetism has a strength of about 0.61 line of force per square centimeter, in the direction of greatest force, which is about 70 degrees below the

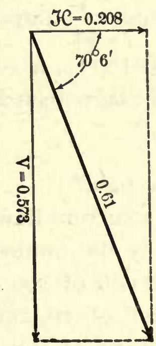


FIG. 244.

horizontal. The force in the horizontal direction, often called "horizontal intensity" or "ℋ," is 0.208, while the vertical component is 0.573 gausses. (See also No. 777.)

245. *What is meant by "4π" as used in connection with electricity or magnetism?*

The Greek letter π (pronounced "pi") is a character adopted by mathematicians to denote the relation between the diameter and the circumference of a circle, and equals 3.1416; that is, the circumfer-

ence of a circle is 3.14 times its diameter. The area of a sphere is 4π (or 12.566) times its radius squared, or π times its diameter squared. For example, if the diameter of a circle is 6 ins., its circumference is 3.14 x 6, or 18.84 ins.; the area of a circle 6 ins. in diameter is 3.14 x 6 x 6, or 113.1 sq. ins.

246. *What does π have to do with electricity?*

The exact relation is rather complicated and mathematical, but, in general terms, it comes from the original unit taken for magnetic force. At unit distance from a unit magnetic pole, the field has unit strength, and there is one line of force per square centimeter; but this force is equal in all directions from the unit pole, and since a sphere with radius equal to unity has a surface of 4π, it follows that there are 4π lines of force coming from a unit pole. In a more complicated way, the magnetic force due to a current flowing through a coil equals $\frac{4\pi}{10}$ times the product of amperes by turns of wire. (See Nos. 136, 224.)

247. *What is a "gilbert?"*

The name "gilbert" has been proposed for the practical unit of magnetomotive force and equals $\frac{1}{4\pi}$ ampere turn. The unit is named after William Gilbert (1540-1603), a court physician in England, who made a careful study of magnetism and wrote the first extended treatise on the subject.

248. *What is an ampere-turn?*

The magnetizing force of a current flowing through a coil varies as the product of the current by the number of turns in the coil. A current of 1 amp. through a coil of 100 turns would have the same magnetic effect as a current of 10 amps. through a coil of ten turns, provided both coils were of similar dimensions, having the same diameter and length. (If any iron is near, it must be assumed the same in the two cases.) In each case the magnetizing force is 4π times 100 amp.-turns, or 1256.6 gilberts.

249. *What is reluctance?*

Reluctance in a magnetic circuit corresponds closely with resistance in an electric circuit. The law for magnetic circuits is very similar to that for electric circuits. The magnetic flux (corresponding to current) equals the magnetomotive force (corresponding to voltage or electromotive force) divided by reluctance.

250. *What is the "oersted?"*

"Oersted" has been proposed for the name of the practical unit of reluctance, being such as to permit one maxwell to traverse it under the action of a magnetomotive force of one gilbert. The unit is named after Hans Christian Oersted (1777 to 1851), a Danish physicist, who discovered the action of a current on an electromagnet.

251. *Are there other electrical units than those noted above?*

Other units, which are not so fundamental as those already discussed, are considered in later numbers; the mho in No. 335, the circular mil in No. 341, the square mil in No. 342, the mil-foot in No. 344, the mile-ohm in No. 357.

For tabular statement of relations between various units, see Appendix II.

CHAPTER III.

LAWS OF ELECTRIC CIRCUITS.

300. *How many kinds of current are there?*

Currents may be classified on the basis of directionality into unidirectional (or direct) and alternating. The latter may be divided into harmonic and irregular. Unidirectional currents may be divided into constant (or continuous), pulsating and irregular currents. Sometimes currents are classified into galvanic (or voltaic) and induced (or faradic) currents.

301. *What are voltaic or galvanic currents?*

This is a name used by physicians for unidirectional steady currents, such as given by a battery to a circuit of steady resistance. When applied to patients they call it galvanization.

302. *What is meant by franklinization?*

This medical term is used for the application of static electricity, that is, electricity of very high pressure and small quantity.

303. *What is meant by faradization?*

This is a medical term referring to the application to patients of interrupted or induced currents.

304. *What is a sinusoidal current?*

A sinusoidal current is a common variety of alternating current in which the current gradually increases from zero to a maximum value,

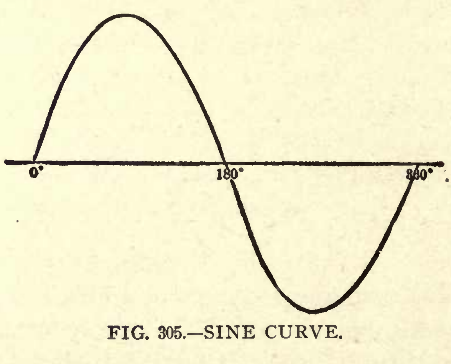


FIG. 305.—SINE CURVE.

then becomes weaker until it reaches zero, then changes direction and rises gradually to a maximum and so on. (See No. 1401.)

305. *What is a pulsating current?*

A pulsating current goes always in the same direction, but changes its strength, not necessarily falling to zero, but rising and falling by more or less regular gradations.

306. *What is an interrupted current?*

One that has nearly constant strength, but one that is off and on at regular intervals.

307 *Is there any difference between the current obtained from a dynamo and that from a battery of equal voltage?*

Current from a battery is steady, while there is a slight pulsation in the current obtained from a dynamo, even if it be a direct-current machine.

308. *Is there any analogy between the flow of electricity and the flow of water?*

The number of amperes in an electric circuit corresponds closely to the number of cubic feet or gallons per minute flowing through a pipe. The electric pressure or voltage corresponds closely to the number of pounds pressure per square inch. The electrical resistance corresponds to some extent to the friction along the surface of the pipes, the difference being that the resistance to the flow of water depends upon both the surface of the pipe and upon its area. The fall of potential or "drop" due to the passage of current through a conductor equals the product of current by resistance, corresponding to the loss of pressure in a pipe proportional to the surface friction of the pipe and to the amount of water flowing. The pump and the dynamo are analogous, while the water motors correspond to the electric motors or lamps. Sometimes water motors are arranged tandem, so that the same water passes through two or more; such an arrangement corresponds closely to a "series" electric circuit. Generally the water motors are arranged so that each takes its own water and receives the full pressure on the mains; this corresponds closely with "multiple arc" electric circuits such as used for motors or incandescent lamps.

309. *Is there any definite direction to the flow of an electric current?*

The magnetic and chemical effects of the current show a directionality. Scientists have agreed to say that a current flows in one direction when certain effects appear, and to say it flows in the opposite direction when these results are reversed; but it is not certain that what is called positive may not actually be negative. By common consent, a current acting in a certain manner is said to flow

in a given direction, the point from which it flows being called positive, and that to which it flows being called negative. This is somewhat analogous to what we call down and up in relation to gravity, although it is not absolutely certain whether a body falls to the ground because it is pulled by the earth or whether it is pushed by some force from outside.

310. *How can the direction of a current be determined from its magnetic effects?*

If the current is of considerable strength, its direction may be shown by a compass needle, or by a small magnet suspended by a thread or fine wire. Place the conductor so that its direction is approximately north and south, hold the magnet or compass just above the conductor and let the observer face the north. If the north-pointing end of the magnet is deflected to the right, the current is going away from the observer; while if the south-pointing end is deflected to the right, the current is coming toward the observer.

Another method is to wind the conductor a few times around an iron rod and note the end which attracts the north-pointing end and repels the south-pointing end of the magnet. The current flows clockwise around the coil as one looks from the attracting pole toward the other.

311. *How can the direction of the current be determined by its chemical effect?*

In a glass containing water acidulated with sulphuric acid (ten parts water, one part acid), place two pieces of clean lead and connect the same to the two poles of the dynamo, putting an incandescent lamp in series as suggested in the figure. The surface of the lead

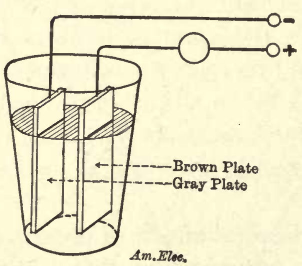


FIG. 311.—POLARITY TEST.

connected to the positive pole will become reddish brown after the current has passed for a short time, and the surface of the other piece will assume a grayish color. This method may be applied

to dynamos for incandescent lamps and for charging storage batteries, but is not suitable for arc machines except by changing the connections. For testing the direction of current from an arc dynamo, the lead cell with the incandescent lamp may be connected in shunt around an arc lamp. The simplest method, however, of testing the direction of current from an arc dynamo is to notice the carbons immediately after the current has been cut off from an arc lamp, when the positive carbon will be found to be much hotter than the negative carbon.

312. *What solution is used for moistening the paper in polarity indicators?*

The simplest solution is iodide of potassium dissolved in water; when paper is moistened with this, and the terminals of a battery or dynamo are connected to it, a brown spot is left at the positive terminal, or where the current enters; the paper must be damp when the test is applied. Adding glycerine to the solution keeps the paper moist longer. By moistening paper with a solution of iodide of potassium, to which some starch water has been added, a blue mark is left at the positive pole. Another solution is made by dissolving 15 grains of red iodide of mercury and 20 grains of iodide of potassium in one fluid ounce of glycerine; this must be used moist, keeping the terminals 1 in. apart for each 100 volts; a yellow mark is left at the negative pole. By using a solution of ferrocyanide of potassium and iron terminals, a blue mark is left at the positive pole.

In applying any of these tests, it is desirable to avoid all risk of making a short circuit. For this reason it is common to place an incandescent lamp in series with the test paper.

313. *What is the potato test for polarity?*

A convenient test is to stick the ends of two wires into a potato, keeping the ends an inch or more apart. When the wires are connected to a charged circuit, the potato will boil at the negative terminal on account of the gas set free by chemical decomposition.

314. *Why do electricians attach so much importance to Ohm's law?*

Because it is the basis of most calculations relating to electricity. It is a very simple law, but its applications are often quite complex and difficult to follow.

315. *What is Ohm's law.*

"The strength of the current varies directly as the electromotive force, and inversely as the resistance of the circuit," is the form in

which it was originally stated by its discoverer, George Simon Ohm, a German electrician who lived from 1789 to 1854. Using the units adopted by modern electricians, the law is: "The number of amperes of current flowing through a circuit is equal to the number of volts of electromotive force divided by the number of ohms of resistance. This may be written,

$$\text{Current (in amperes)} = \frac{\text{Electromotive force (in volts)}}{\text{Resistance (in ohms)}}.$$

316. *Is there a shorter statement of Ohm's law?*

"Current equals pressure divided by resistance," or "amperes equal volts divided by ohms." A still shorter form is to write simply the initial letters from above equation,

$$C = \frac{E}{R}, \text{ or } I = \frac{E}{R}.$$

Although "C" is the natural abbreviation for current, the standard practice is to use the letter "I" to represent current.

317. *What is an ampere?*

The ampere (named after Andre Marie Ampere, a French physicist who lived from 1775 to 1836) is the unit of current. Defined in terms of other units, the ampere is the strength of current necessary to carry one coulomb (see Nos. 137 and 229) in one second. It is the current which an electromotive force of one volt (see Nos. 138 and 228) will send through a circuit whose resistance is one ohm (see Nos. 226 and 234). It is the current which, passing through 1 cm. of wire bent into part of a circle of 1 cm. radius, would attract or repel a unit magnet pole at the center of the circle with a force equal to one-tenth dyne. It is one-tenth of the "absolute" or "C. G. S." unit of current. It is a current which will deposit silver from a standard solution at the rate of 0.001118 gram per second. (See also No. 227.)

318. *What is an ohm?*

The ohm is the unit of electrical resistance. Theoretically, it is a velocity of one earth-quadrant per second; that is, the speed required to travel from the earth's equator to its pole in one second. (For the practical ohm, see Nos. 226 and 234.)

319. *How is Ohm's law used in electrical calculations?*

If two of the three quantities are known, the other can be calculated easily by simple rules of arithmetic.

320. *Does Ohm's law take other forms than* $I = \frac{E}{R}$ *?*

It may be written $E = I R$ or $R = \frac{E}{I}$

To illustrate, suppose in an electrical circuit in which 5 amp. are flowing that the E.M.F. is ten volts, and that the entire resistance of the circuit is two ohms. Then we have

$$I = \frac{E}{R} = \frac{10}{2} = 5;$$

$$R = \frac{E}{I} = \frac{10}{5} = 2;$$

$$E = I R = 5 \times 2 = 10.$$

321 *How much current will* 100 *volts send through a circuit of* 5 *ohms?*

Since current equals voltage divided by resistance, the current in this case is 100 divided by 5, or 20 amp.

322. *How much electromotive force is necessary to send* 10 *amp. through* 4.5 *ohms?*

Since voltage equals current multiplied by resistance, it requires 10 times 4.5, or 45 volts.

323. *Through what resistance will* 50 *volts send* 2 *amp.?*

Resistance equals voltage divided by current. Hence, in this case, resistance equals 50 divided by 2, or 25 ohms.

324. *What is the resistance of a* 16-*cp. incandescent lamp, through which* 110 *volts send a current of* 1-2 *amp.?*

Since resistance equals voltage divided by current, the resistance of the lamp is 110 divided by 0.5, or 220 ohms.

325. *Does Ohm's law hold true for every part of a circuit, as well as for the whole circuit?*

It does when properly applied. The pressure required to send current through any part of a circuit equals the product of the current by the resistance of that part of the circuit.

326. *How does Ohm's law apply when there are several parts in a circuit?*

The total current equals the total electromotive force divided by the total resistance. There may be several currents, several electromotive forces and several resistances in the same circuit. The conditions of each circuit must be considered before applying the law.

327. *What is a series circuit?*

A series circuit is one consisting of several parts connected "in series" or in a row, so that the same current passes through each part one after the other.

328. *Give an example where several resistances are in series.*

A telegraph line is a good example, the circuit consisting of the line wire, the keys and relays, the batteries and the earth return.

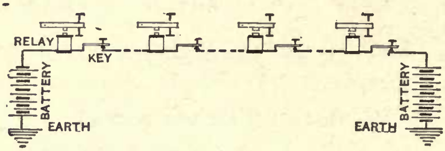


FIG. 328.—TELEGRAPH CIRCUIT.

Suppose the line consists of 100 miles of No. 8 iron wire having a resistance of 12.6 ohms per mile, 15 relays of 150 ohms each, two batteries of 50 cells of 4 ohms each, and the earth return with a resistance of 25 ohms. The resistance of the line is 100 times 12.6, or 1260 ohms; that of the relays is 15 times 150, or 2250 ohms; that of the batteries is 50 times 4, or 200 ohms for each battery, or 400 ohms for the two. The total resistance of the circuit, allowing 25 ohms for resistance of keys and contacts, is the sum of 1260 plus 2250 plus 400 plus 25 plus 25, which equals 3960 ohms, or,

$$R = (12.6 \times 100) + (150 \times 15) + (4 \times 50 \times 2) + 25 + 25.$$
$$R = 1260 + 2250 + 400 + 25 + 25.$$
$$R = 3960 \text{ ohms}.$$

329. *How can the current in such a line be calculated?*

The batteries give an average of about 1.07 volts per cell, hence the 100 cells give an electromotive force of 107 volts. The current equals voltage divided by resistance, or 107 divided by 3960, which equals 0.027 amperes, or 27 milli-amperes.

330. *Are series circuits used in electric lighting?*

Arc and incandescent lamps for street lighting are generally in series circuits supplied with current of constant strength, either direct or alternating. For example, a direct current open arc lamp, such as formerly used for street lighting, required 50 volts with 6.8 or 9.6 amperes, thus having an effective resistance of about 7.5 or 5.2 ohms. For 9.6 amperes, the line is made of No. 6 copper wire,

having a resistance of about 2.1 ohm per mile. A circuit 15 miles long with 60 open arc lamps with 9.6 amperes has a resistance equiv-

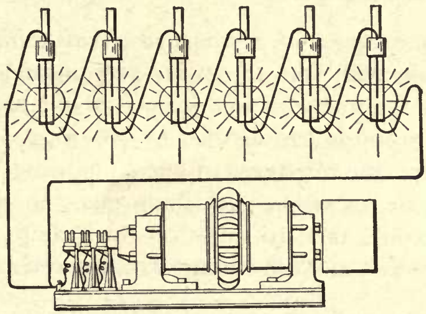


FIG. 330.—SERIES ARC LIGHT CIRCUIT.

alent to about 60 times 5.2 ohms for the lamps, plus 15 times 2.1 ohms for the line, or 312 plus 31.5, or 343.5 ohms; or

$$R = (60 \times 5.2) + (15 \times 2.1) = 312 + 31.5 = 343.5 \text{ ohms.}$$

The voltage at the dynamo necessary to send 9.6 amperes through the circuit is about 9.6 times 343.5, or about 3298 volts; or

$$E = I\,R = 9.6 \times 343.5 = 3298 \text{ volts.}$$

331. *What is a multiple circuit?*

A multiple circuit is one that is branched so that the current divides in several paths. Such a circuit may be called "multiple arc," "multiple," "parallel," "branched," or "divided." The parts may be said to be connected "in multiple," "in parallel," "in multiple arc," "in derivation," or "in shunt." (See Figs. 638, 901, 1146, 1410.)

332. *What is the resistance of a multiple circuit?*

It is obtained most easily by considering the conductivity, which is the reciprocal of the resistance. The conductivity of the whole equals the sum of the conductivities of the parts, hence the resistance of the whole equals the reciprocal of the sum of the conductivities, or the resistance of the whole equals the reciprocal of the sum of the reciprocals of the resistances of the separate parts. For a circuit of three branches, this may be expressed in a formula as follows:

$$R = \frac{1}{K} = \frac{1}{K' + K'' + K'''} = \frac{1}{\frac{1}{r'} + \frac{1}{r''} + \frac{1}{r'''}} = \frac{r'\,r''\,r'''}{r'\,r'' + r'\,r''' + r''\,r'''}$$

One way of expressing the joint resistance is to say that the resistance of a branched circuit equals the product of all the parts, divided by the sum of the products of each part by every other part

except one. When the parts are equal, the formula reduces to a simple form, and the joint resistance equals that of one part divided by the number of equal parts.

333. *Give an example of a branched circuit with equal parts.*

Take a circuit with ten 16-cp 110-volt incandescent lamps in multiple. The resistance of one lamp is about 220 ohms; the reristance of the group is 220 divided by 10, or 22 ohms. This can be checked easily: the resistance of one lamp being 220, it takes 110 divided by 220, or 0.5 amp.; each lamp takes an equal amount, so the ten lamps would take 10 times 0.5, or 5 amp.; by Ohm's law, when the current is 5 and the voltage 110, the resistance is 22 ohms.

334. *Give an example of a branched circuit with unequal parts.*

An incandescent lighting circuit divides into three circuits, having five, eight and ten lamps, respectively. The resistances of these branches are therefore 44, 27.5 and 22 ohms; their conductivities are 0.0228, 0.0364 and 0.0455 "mhos;" the sum of their conductivities is 0.10454 mho, and the reciprocal of this sum is 9.56 ohms. This may be checked as follows: The first branch takes 110 divided by 44, or 2.5 amp.; the second branch takes 4 amp., and the third branch 5 amp., making a total of 11.5 amp.; to take this current, the resistance is 110 divided by 11.5, or 9.55 ohms.

335. *What is a "mho?"*

The mho is the unit of conductivity and is the reciprocal of the conductivity. For example, a conductor with resistance of 5 ohms has a conductivity of 1-5 or 0.2 mho.

336. *What are series-multiple or multiple-series circuits?*

Practice is somewhat divided in the use of these words. With some, a multiple-series circuit means a circuit consisting of a multiple of series circuits; others mean multiple circuits in series. The two are suggested in the accompanying figure. Examples of mul-

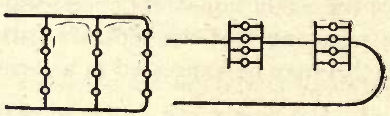


FIG. 336.—SERIES MULTIPLE AND MULTIPLE SERIES CIRCUITS.

tiple-of-series circuits are seen in the lighting circuits of street cars, in which five incandescent lamps are connected in series, and several of these circuits are connected in multiple across the 500-volt line. Series-of-multiple circuits were formerly used for operating

incandescent lamps on arc circuits, the current being divided among several lamps, so that each lamp took only part of the whole current; these systems proved to be sources of fire risk, and have been abandoned.

337. *Are multiple-series circuits used for any purpose except for lighting from electric railway circuits?*

Incandescent electric lamps for street lighting purposes are commonly operated on multiple-series circuits. The "municipal system," formerly sold by the Edison Company, has a direct-current dynamo

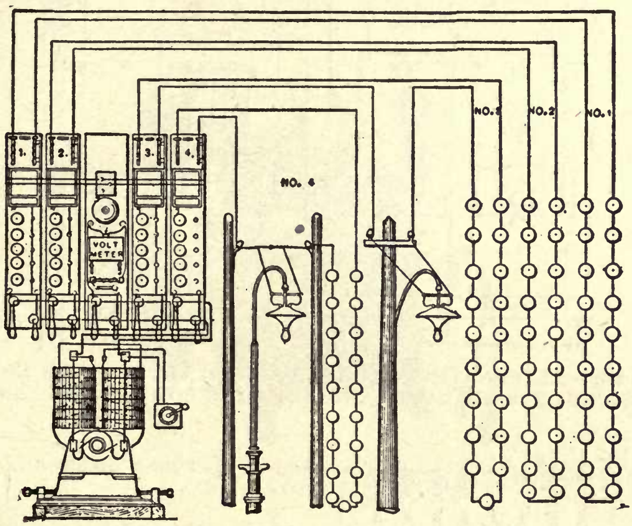


FIG. 337A.—EDISON MUNICIPAL SYSTEM.

giving about 1200 volts. A "string" of twenty or more incandescent lamps taking 4 amp. was connected in series with an adjustable lamp board or "bank board," having an ammeter and a number of lamps which could be switched into the circuit when needed. Several strings of lamps were connected to one dynamo, enough lamps being in each circuit so that the 1200 volts would send the required 4 amperes through the circuit. With alternating currents the outside and inside lamps are operated from the same generators, and even from the same circuits, as indicated in Fig. 337B, in which the street lamp current is controlled by cutting in more or less lamps at the station. The Westinghouse Company shunts each lamp by a coil which normally takes little current, but which carries the whole current when the lamp breaks, and substitutes a counter-electro-

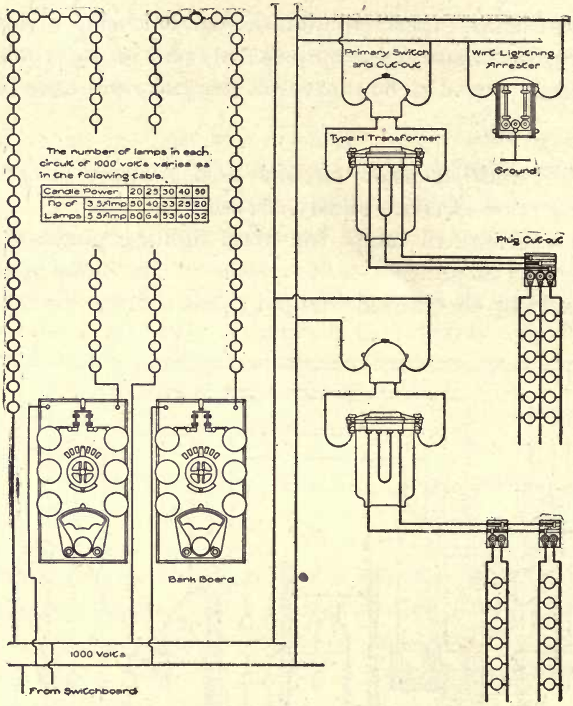


FIG. 337B.—ALTERNATING CURRENT SYSTEM WITH SERIES INCANDESCENT STREET LAMPS AND MULTIPLE COMMERCIAL LAMPS

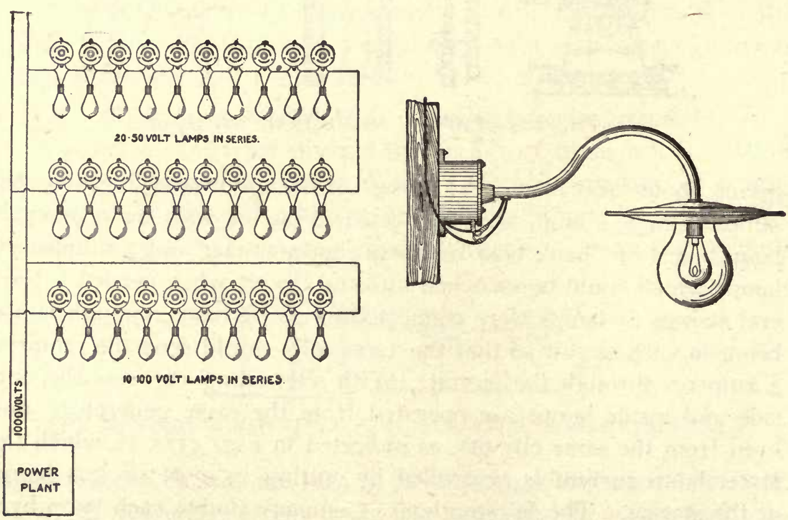


FIG. 337C.—WESTINGHOUSE INCANDESCENT SERIES STREET LIGHTING SYSTEM.

motive force for the ohmic drop through the lamp (see Nos. 361 and 1477). The late practice is to use special transformers giving constant current and insulating the street circuit.

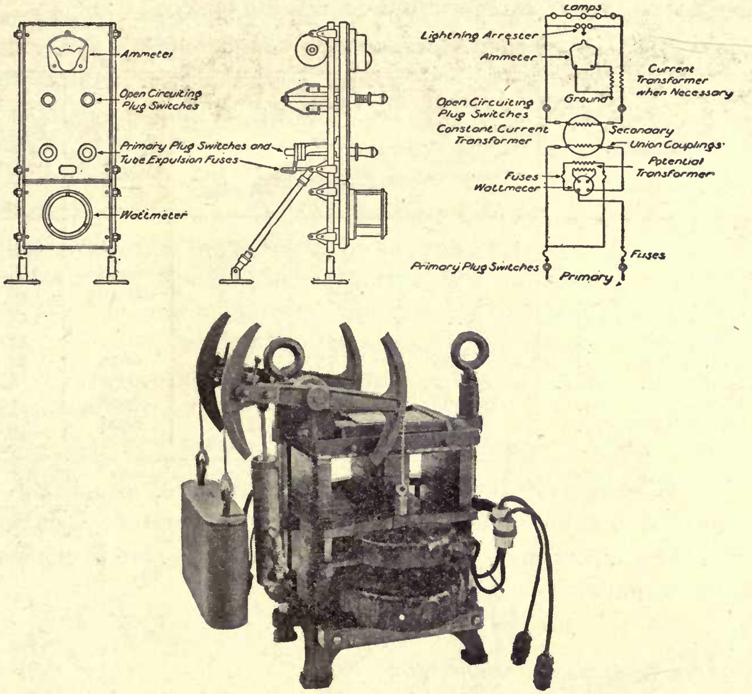


FIG. 337D.—GENERAL ELECTRIC INCANDESCENT SERIES STREET LIGHTING SYSTEM.

338. *What is the difference between a conductor and a resistance?*
It is a question of degree and purpose. No substance is a perfect conductor, therefore every conductor offers more or less resistance to a current. If one wishes to increase the resistance of a circuit, he puts in series a conductor of the desired resistance. If he desires to reduce the resistance, that is, to increase the conductivity of the circuit, the conductors are replaced by others of higher conductivity, or several conductors are connected in multiple.

339. *What determines the resistance of a conductor?*
The resistance increases directly as the length, inversely as the sectional area, and depends upon the "specific resistance" of the material of which the conductor is composed.

340. *What is meant by specific resistance?*
The specific resistance is commonly taken as the resistance, in

millionths of an ohm, between the parallel faces of a cube of material 1 cm. in each dimension. In practical engineering the resistance of a mil-foot is often taken as the unit. Values for substances commonly used as conductors are given in the following table.

SPECIFIC RESISTANCE OF CONDUCTORS

Conductor	Specific Resistance (Microhms Per Cubic Centimeter)	Resistance of One Mil-Foot.		Temperature Coefficient per Degree Centigrade	Percentage Conductivity
		0 Cent. 32 Fahr.	24 Cent. 75 Fahr.		
Copper	1.594	9.59	10.507	.00388	100.
Silver	1.50	9.4	10.16	.00380	106.
"EBB" iron	9.75	58.6	65.3	.00463	16.2
"BB" iron	....	....	78.5	......	13 5
Steel (wire)	....	....	90.8	.....	11.6
Aluminum	2.889	17.75	19.4	.0039	54.5
Lead	19.63	115.5	129.	.00387	8.2
Mercury	94.07	600.	613.	.00089	1.73
German silver	20.76	126.	127.2	.0004	8.3

The resistance at any temperature (above zero) equals the resistance at zero multiplied by one plus the "temperature coefficient" times the temperature (in Centigrade degrees). This is expressed by the formula,

$$Rt = Ro\ (1 + \alpha t).$$

341. *What is a circular mil?*

The circular mil is the unit used in measuring the area of conductors. It is the area of a circle one mil, that is, one one-thousandth of an inch in diameter.

342. *What is a square mil?*

The square mil is sometimes used as a unit of area, being the area of a square one one-thousandth of an inch on each side.

343. *What is the relation between circular mils and square mils?*

The number of circular mils multiplied by 0.7854 gives the number of square mils. Square mils multiplied by 1.273 equals circular mils. These figures give the relation between the area of a circle and the surrounding square.

344. *What is a mil-foot?*

The mil-foot is a wire of cylindrical section, having a diameter of 1 mil (that is, one one-thousandth of an inch) and 1 ft. long. The resistance of a mil-foot of pure copper at the temperature of melting ice is 9.59 ohms; it weighs 0.000003027 pounds.

345. *Is the resistance of a conductor affected by the temperature?* The resistance of metal conductors increases about four-tenths of 1 per cent for each degree Centigrade rise in temperature, or about twenty-two-hundredths of 1 per cent for 1 deg. F. The resistance of carbon, liquids and a few alloys decreases with rise of temperature. German silver, manganin, "IA IA," etc., change little.

346. *Is resistance affected by pressure?* The resistance of a solid continuous conductor is not affected by pressure. The resistance of a conductor containing loose connections, such as a powder or a pile of plates lying loosely upon one another, is diminished by pressure, since the parts are brought closer together. The resistance at the surface of carbon is more sensitive to pressure than that of other substances, and this has been usefully applied in certain forms of carbon rheostat, also in the telephone transmitter.

347. *How is the variable resistance of carbon utilized in the telephone transmitter?*

This may be illustrated from the Hunnings transmitter, which is the basis of most modern transmitters. In the accompanying figure,

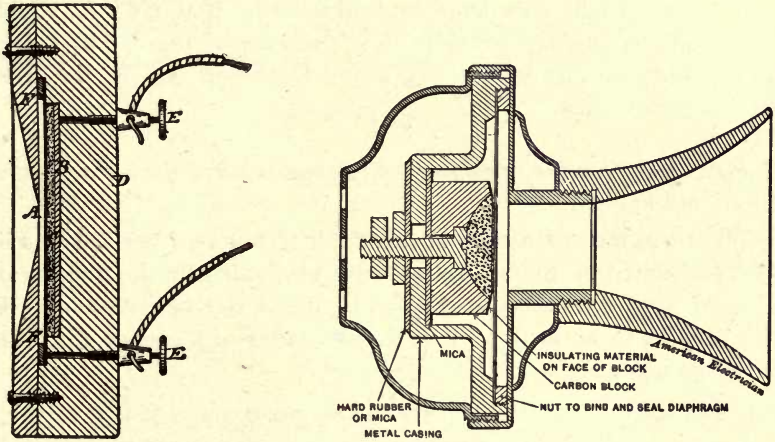


FIG. 347.—TELEPHONE TRANSMITTERS.

C represents granulated carbon, which is held between a solid back, *B*, and the diaphragm, *A*, so that the circuit between the binding posts, *EE*, is through the back, *B*, the carbon particles, *C*, and the diaphragm *A*. When a person speaks in front of the transmitter, the diaphragm is thrown into vibration and thus presses against the carbon particles more or less, and so varies the resistance, and consequently the current varies with each vibration of the voice. The figure shows also an improved modern form.

348. *How can the resistance of a wire be determined?*

The simplest way is to test its size by a wire gage and find the resistance from a table. Instead of using a wire gage, the diameter may be measured by a micrometer, and the resistance may then be calculated or may be taken from a table.

349. *How can the circular mils in a wire be calculated from its diameter?*

When the section of a wire is circular, the area equals the diameter squared. By geometry it is shown that the areas of circles are to each other as their diameters squared. Taking the area of a circular mil as the unit, the area of any round wire equals the square of its diameter measured in thousandths of an inch; thus the area of a wire having a diameter of 102 thousandths of an inch is 102×102, or 10404 circ. mils.

350. *How can one calculate the number of circular mils in a bar of rectangular section, such as a bus-bar?*

It is most easily calculated by remembering that 1 sq. in. equals 1,273,000 circ. mils. Therefore, find the area of the bar in square inches and multiply by 1,273,000, and the result will be the cross section in circ. mils.

351. *How can the resistance be calculated when the diameter and length are known?*

The resistance of a wire equals the resistance of a circular mil-foot multiplied by the length in feet and divided by the number of circular mils in its area, or divided by the square of its diameter in thousandths of an inch. Thus, the resistance of a copper wire .102 in. in diameter and 1000 ft. long is,

$$\frac{10.5 \times 1000}{102 \times 102} = 1.01 \text{ ohm.}$$

In practice it is common to take 11 as the resistance of a mil-foot, thus allowing for variations in diameter, conductivity and imperfect connections. The rule is often written as a formula:

$$\text{Resistance} = \frac{11 \times \text{length}}{\text{diameter squared}} = \frac{22 \times \text{distance}}{\text{diameter squared}}, \text{ or,}$$

$$R = \frac{11\,L}{d^2} = \frac{22\,D}{d^2}.$$

352. *How can the size be determined to give a certain resistance in a wire of a certain length?*

The formula in No. 351 can be easily changed, showing that the circular mils, or the square of the diameter of the wire, equals the length multiplied by the resistance per mil-foot divided by the required resistance (see also Nos. 367 to 371), or,

$$\text{c. m.} = d^2 = \frac{11 \times L}{R} = \frac{22 \times D}{R}.$$

353. *Give an example showing how the formula is used.*

A wire 1 mile long is required to have a resistance of 2 ohms.

$$\text{c. m.} = \frac{11 \times 5280}{2} = 28000 \text{ circ. mils;}$$

this is a little larger than No. 6 B. & S. G. If it were necessary to make the line have the exact resistance stated, it might be made partly of No. 6 and partly of No. 5.

354. *How can one calculate the length of wire necessary to give a desired resistance?*

The length equals the resistance multiplied by the square of the diameter and divided by the resistance of a mil-foot, or,

$$L = \frac{R\ d^2}{k}$$

355. *What must be the length of a German silver wire* 0.016 *in. in diameter to make* 200 *ohms?*

The resistance of a mil-foot of German silver is about 127 ohms, varying to some extent in different lots. For 200 ohms the required length is,

$$L = \frac{200 \times 16 \times 16}{127} = 403.1 \text{ ft.}$$

356. *What is the resistance of* 100 *ft. of "EBB" telephone wire* 0.064 *in. in diameter?*

Resistance equals the resistance of a mil-foot multiplied by the length and divided by the area, or by the square of the diameter. The resistance of "EBB" iron wire is 65.3 ohms per mil-foot at 75 degs. F. Therefore,

$$R = \frac{65.3 \times 100}{64 \times 64} = \frac{6530}{4096} = 1.6 \text{ ohms.}$$

357. *What is a mile-ohm?*

The mile-ohm is a term used in connection with telegraph and telephone wire. It is the resistance of a wire 1 mile long and weighing

1 lb. The mile-ohm of pure iron is about 4000, the specifications of the Western Union Company calling for not more than 4800, the British office calling for not more than 5323. The "mile-ohm" is really an abbreviation for "weight per mile-ohm," and is sometimes called "pound-mile-ohm." The former specifies "the electrical resistance of the wire in ohms per mile, at a temperature of 68 degs. F., must not exceed the quotient arising from the dividing the constant number 4800 by the weight of the wire in pounds per mile. The coefficient .003 will be allowed for each degree Fahrenheit in reducing to standard temperature." One mile-ohm of copper at 60 degs. F. equals 859 international ohms, or 861 legal ohms, or 868.9 B. A. units.

358. *What wire gages are in common use?*

That in most common use in America is the Brown and Sharp gage, often abbreviated to "B. & S. G.," and frequently called American gage. Iron wire is generally made according to the Birmingham wire gage, often abbreviated to "B. W. G." Other gages sometimes used are the Washburn & Moen, Roebling, and the New British or Standard gage. Wires are often designated by their diameters without reference to any gage. Very large cables or bars are usually designated by their diameter or area in mils. (See tables on pages 79 and 92.)

359. *Are there any easy rules for remembering the wire table?*

A B. & S. G. wire three sizes larger than another has half its resistance, twice its weight and twice its area. A wire ten sizes larger than another has one-tenth its resistance, ten times its weight and ten times its area. The relative values of resistance (for decreasing sizes)—and of weight and area for *consecutive* sizes are: 0.50, 0.63, 0.80, 1.00, 1.25, 1.60, 2.00. The relative diameters of *alternate* sizes of wire follow the same schedule. No. 10 wire has a diameter of 0.10 inch (102 mils), an area of 10,000 circ. mils (10,380), a resistance of 1 ohm per 1000 feet at 20 deg. cent. (68 F.) and weighs 31 pounds (31.4) per 1000 feet. No. 5 wire weighs 100 pounds per 1000 feet. The safe carrying capacity doubles every fourth size.

360. *Is a circuit likely to have more than one electromotive force?*

The principal E.M.F. causing current to flow in the circuit may be in one or more sections, which may be in one or more parts of the circuit. Besides these there may be opposing E.M.F's, or counter E.M.F's, which may or may not vary with the amount of current in the circuit. The fall of potential as the current overcomes resistance is sometimes called an E.M.F., as it is measured in volts, although it is more common to call it "ohmic drop" or simply "drop."

TABLE SHOWING THE DIFFERENCE BETWEEN WIRE GAGES.

No.	Brown & Sharpe	Birmingham, or Stubs	New British Standard	Roebling, or Washborn & Moen.
0000	.460	.454	.4	.393
000	.40964	.425	.372	.362
00	.36480	.380	.348	.331
0	.32486	.340	.324	.307
1	.28930	.300	.3	.283
2	.25763	.284	.276	.263
3	.22942	.259	.252	.244
4	.20431	.238	.232	.225
5	.18194	.220	.212	.207
6	.16202	.203	.192	.192
7	.14429	.180	.176	.177
8	.12849	.165	.16	.162
9	.11442	.148	.144	.148
10	.10189	.134	.128	.135
11	.09074	.120	.116	.12
12	.08081	.109	.104	.105
13	.07196	.095	.092	.092
14	.06408	.083	.08	.08
15	.05707	.072	.072	.072
16	.05082	.065	.064	.063
17	.04526	.058	.056	.054
18	.04030	.049	.048	.047
19	.03589	.042	.04	.041
20	.03196	.035	.036	.035
21	.02846	.032	.032	.032
22	.025347	.028	.028	.028
23	.022571	.025	.024	.025
24	.0201	.022	.022	.023
25	.0179	.020	.02	.02
26	.01594	.018	.018	.018
27	.014195	.016	.0164	.017
28	.012641	.014	.0148	.016
29	.011257	.013	.0136	.015
30	.010025	.012	.0124	.014
31	.008928	.010	.0116	.0135
32	.00795	.009	.0108	.013
33	.00708	.008	.01	.011
34	.0063	.007	.0092	.01
35	.00562	.005	.0084	.0095
36	.005	.004	.0076	.009
37	.00445	....	.0068	.0085
38	.003965	....	.006	.008
39	.003531	....	.0052	.0075
40	.003144	...	.0048	.007

361. *What are the distinctions between E.M.F., C.E.M.F., fall of potential, drop, pressure, difference of potential and ohmic drop?*

E.M.F. generally refers to the primary cause of the current, or the "electricity moving force." Ohmic drop, or simply drop, refers to the fall of potential caused by the resistance met by the current, and equals the product of current by resistance; the drop may refer to the resistance of the entire circuit, or to that in any specified part of it. Counter electromotive force is usually a result of the passage of the current causing some inductive, chemical, or equivalent action, which would of itself tend to send a current in the opposite direction, a simple case being a storage battery while charging. C.E.M.F. is the principal factor regulating the current taken by a motor or transformer. C.E.M.F. is not always or necessarily simply proportioned to the strength of the current. Fall of potential is a general term, including drop and C.E.M.F. Pressure and difference of potential are general terms referring to any of the others. Voltage is a general term similar to difference of potential, but in addition calling attention to the unit used in its measurement.

362. *Can each of these quantities be measured?*

All can be measured directly except C.E.M.F., and sometimes E.M.F. An electromotive force can generally be measured by opening the circuit and connecting a voltmeter or its equivalent to the terminals of the source of current. When this can not be done, the total E.M.F. equals the voltage at the terminals plus the ohmic drop through the generator. Likewise, C.E.M.F. is calculated by subtracting the ohmic drop from the voltage between the terminals.

363. *Does applying a certain E.M.F. to a conductor having one end insulated raise the whole of the conductor to that E.M.F., irrespective of its length?*

When no current is flowing through a conductor, it usually has the same potential throughout its length, except when it is charged inductively. For example, suppose that one terminal of a battery (say the negative) giving 10 volts is connected to the earth, while the other terminal (the positive) is connected with one point of an insulated wire. There is then a difference of potential of 10 volts between the earth and the positive terminal of the battery; the same difference of potential exists betwen the earth and every part of the insulated wire, provided it is not acted upon by any E.M.F. other than that of the battery. If, however, the insulated wire be connected with the earth either directly or through a resistance, current will flow through the wire, causing a fall of potential equal to product

of current by resistance; the difference of potential between the wire and the earth then falls from about 10 at the battery terminal toward zero at the point of contact with the earth. When a conductor is charged inductively, somewhat as discussed in Nos. 99 to 101, the potential may vary in different parts when no current flows. For example, suppose that one end of a conductor is near a body charged negatively, while the other end is grounded; the difference of potential between the earth and the conductor then varies from zero at the grounded end to a maximum at the end nearest the charged body.

364. *To what difference of potential would a person be subjected if he should touch a circuit of five incandescent lamps connected in series between the trolley wire and the ground, as in a trolley car?*

The total voltage, or difference of potential, between the trolley and the ground, which is usually about 500 volts, would ordinarily be divided nearly equally among the different lamps. If a person should stand on the rail or on wet ground and should touch the circuit above the lamp nearest the ground, he would receive a shock due to approximately 100 volts; touching the circuit between the second and third lamps, he would get 200 volts, and so on. It would be somewhat risky to touch the circuit at higher points. The severity of a shock varies with the voltage, the current, the part of the body affected and the general state of the person, some being much more sensitive than others. It is believed that one-tenth of an ampere through a vital part of the body will prove fatal. The current received will obey Ohm's law and will depend on the resistance of the circuit. The resistance of the human body varies from about 600 ohms in the case of criminals fastened in the electrocution chair, to as high as 80,000 ohms between the fingers of two hands. The resistance varies with different people and with the cleanness and moisture of the skin. The current received will also depend largely upon the resistance between the person and the ground; if one stands on a dry wooden platform, the resistance to ground is high and he can touch the trolley with impunity; if he stands on the rail or on wet ground, he is apt to get a severe or even fatal shock, unless he wears insulated shoes.

365. *How does Ohm's law apply to a circuit containing C.E.M.F.?*

The C.E.M.F. may be considered as reducing the total E.M.F., and Ohm's law becomes: Current equals E.M.F. minus C.E.M.F. divided by resistance, or (see Nos. 1347 to 1373, 1405, 1420),

$$I = \frac{\text{E.M.F.} - \text{C.E.M.F.}}{\text{R}}.$$

366. *Give an example showing the effect of C.E.M.F.*

A 75-hp railway motor has a resistance of about 0.175 ohm. If resistance alone determined the current, it would take 2860 amperes on a 500-volt circuit. Actually the current varies from about 20 to about 200 amperes. When the current is 100, the ohmic drop is 17.5 and the C.E.M.F. is the difference between 500 and 17.5, that is, 482.5 volts.

367. *How can the drop on a line be calculated?*

The drop equals the product of current by resistance, and therefore equals the product of current by length of wire by resistance per mil-foot divided by the square of the diameter, or for copper wire,

$$e = \frac{11 \times L \times I}{d^2} = \frac{11 \times L \times I}{\text{c. m.}}$$

When the outgoing and return wire are of equal length, the distance between the supply and demand is used instead of the length of the wire, the distance being taken as one-half the length of the wire. The formula then becomes, drop equals current multiplied by distance by twice the resistance per mil-foot divided by diameter squared or by circular mils, or

$$e = \frac{22 \times D \times I}{d^2} = \frac{22 \times D \times I}{\text{c. m.}}$$

368. *Give an example showing the calculation of drop on a line.*

Suppose current of 100 amp. is carried from a dynamo to a motor 200 ft. away by a copper wire having a diameter of 0.325 in. The drop is

$$e = \frac{22 \times 200 \times 100}{325 \times 325} = \frac{440{,}000}{105{,}625} = 4.2 \text{ volts.}$$

369. *How can one determine the size wire required to carry a current to a given distance with a given loss?*

The formula in No. 367 may be used, being transformed for greater convenience into the form,

$$\text{c. m.} = \frac{22 \times D \times I}{e} = \frac{22 \times D \times I}{E \times \%} = K\,D\,I$$

or, circular mils equal 22 times distance by amperes, divided by drop in volts or in per cent. of voltage delivered. When a number of calculations are to be made for the same drop, as in wiring a building, it is convenient to reduce 22/e or 22/%E into a single factor *K*. This saving of labor may be carried further by using wiring tables.

370. *Give examples showing how the formula is used.*

Suppose it is required to carry 10 amp. 80 ft. with a drop of one volt. The circular mils required in the conductor are:

$$\text{c. m.} = \frac{22 \times 80 \times 10}{1} = 17600,$$

which is a little larger than No. 8 B. & S. G. Since No. 8 has 16510 circ. mils, and the next larger number, No. 7, has 20820 circ. mils, it is seen that No. 8 is the nearest number, and this would be used.

Suppose it is required to find the size wire necessary to carry 16 amp. 120 ft. with a loss of 2 per cent on a 110-volt circuit. The circular mils required are:

$$\text{c. m.} = \frac{22 \times 120 \times 16}{110 \times 0.02} = \frac{42240}{2.2} = 19200;$$

this is almost as large as No. 7 B. & S. G., which would be used.

371. *How much power is lost in a line?*

The power lost in the line equals the product of current by ohmic drop, or the product of current by current by line resistance, or current squared times resistance (see Nos. 211, 213, 218, 361, 374). To reduce the loss on the line, while delivering a certain amount of power, it is necessary to reduce either the resistance or the current. Reducing the resistance involves using larger wire, which costs money; the current may be reduced by raising the voltage at the load, for the power delivered to the load equals the product of current by voltage.

For example, suppose it is desired to deliver 48.4 kilowatts over a line of 0.05 ohm resistance. At 110 volts delivered, we have:

Current $= I = W/E = 48400/110 = 440$ amperes;

Line drop $= e = Ir = 440 \times 0.05 = 22$ volts $= 20$ per cent.

Line power loss $= Ie = 440 \times 22 = 9680$ watts $= 20$ per cent.

If the load could be arranged for 220 volts delivered, we have:

Current $= I = W/E = 48400/220 = 220$ amperes.

Line drop $= e = Ir = 220 \times 0.05 = 11$ volts $= 5$ per cent.

Line power loss $= Ie = 220 \times 11 = 2420$ watts $= 5$ per cent.

It is thus seen that doubling the voltage for delivering a given amount of power, cuts the power loss and the percentage line drop to one-fourth. In other words, the line loss varies inversely as the square of the voltage delivered. Engineers therefore desire to use as high voltage as practicable. For distribution circuits, the limit is determined by considerations of vested interests and safety in the receiving apparatus such as lamps and motors; for transmission circuits, insulation governs.

372. *How are wiring tables made?*

Four factors are combined in tabular form: (1) the drop, either in volts or in percentage of line voltage; (2) the current, or lamps (to be multiplied by current per lamp), or horsepower (to be multiplied by current per horsepower at assumed voltage); (3) the length of wire or distance between supply and load; (4) the size of conductor, in diameter, area or gage number. Assuming any one of the four factors constant, such as drop, two series of values are assumed for two other factors; corresponding values are then calculated for the remaining factor. The two series of assumed values are the headings for lines and columns. In calculating or using wiring tables, care should be taken not to exceed the current carrying capacity limits of the insurance rules. (See No. 418.)

373. *Is the per cent drop calculated from the voltage at the dynamo, or that at the lamps?*

It is commonly calculated from the volts at the lamp, but ordinarily it does not make sufficient difference to change the size wire a single number, so that either voltage may ordinarily be taken as the base.

374. *Are the above rules for wiring correct for circuits carrying alternating currents?*

They are correct for distances usually met in interior wiring. For circuits several miles long, induction effects are liable to cause a greater drop than is indicated by the simple rules. For such cases, the calculations are more complicated. An excellent discussion of the subject, with convenient tables and curves, may be found in a paper by Mershon in *American Electrician,* June, 1897, Vol. IX., page 221. See also Section 11 of Standard Handbook for Electrical Engineers.

375. *Does Ohm's law apply to circuits carrying alternating currents?*

Not always in its simple form. In a series circuit, the sum of the separate voltages, or drops, may be considerably greater than the total E.M.F. In fact, any one of the several E.M.F's may be greater than the whole. Also in a branched circuit, the current in one branch may be greater than the whole. With a given E.M.F. impressed on a circuit, the current depends not simply upon the resistance, but also upon the self-induction and capacity of the circuit and upon the frequency. This subject is considered in Chapter XII. under "Alternating Currents."

376. *What are good books on electrical wiring construction?*

"Electrical Contracting," by L. J. Auerbach; "Electric Light Wiring," by C. E. Knox; "Modern Electrical Construction," by Horstman and Tousley; "Wiring Handbook," by C. P. Poole; "Standard Wiring," by Cushing.

CHAPTER IV.

ELECTRICITY AND HEAT.

400. *What is the relation between electricity and heat?*

Since both are forms of energy, one may be changed into the other. It is easy to change electrical energy into heat energy with perfect efficiency, so that the heat developed is equal to the electrical energy transformed. It is not so easy to change heat energy into electrical energy, the processes being apparently more complicated and being less efficient. It is practicable to change 1000 watts of electrical energy into an equal amount of heat energy, but 1000 watts of heat energy can not be changed into 1000 watts of electrical energy by any process yet developed.

401. *How can heat energy be changed into electrical energy?*

The most familiar method is to apply the heat to a steam boiler and drive an engine and dynamo. A good boiler will transfer to the water and steam about 80 per cent of the energy in the fuel; a good steam engine will change from 10 to 20 per cent of the total energy of the steam into mechanical energy; a good dynamo will change from 80 to 97 per cent of the mechanical energy received into electrical energy available for use. Putting these together gives an efficiency of from 6 to 15 per cent of the heat energy available as electrical energy, the rest being untransformed heat energy. By the use of gas generators and gas engines driving dynamos, a somewhat higher efficiency may be obtained. An efficiency of nearly 50 per cent is claimed for certain forms of gas battery in which the energy in the gas is changed into electrical energy through chemical action, but such devices have not been reduced to a commercial basis. By the thermopile a theoretical efficiency of about 12 per cent is possible, although about 3 per cent is the highest actually obtained.

402. *What is meant by a thermo-couple?*

A thermo-couple is an electric circuit containing two conductors of two different materials, which will cause a thermo-electric current when their two junctions are at different temperatures. A common case is that of a circuit made up partly of iron wire and partly of copper or of German silver. In fact, thermo-electromotive forces are set up in any circuit in which there is any lack of uniformity of

material and temperature. A circuit made up partly of hard copper wire and partly of the same wire that has been softened by annealing will have thermo-electric currents set up if the wire is heated at the point where the hard wire joins the soft wire. The amount of the current is governed, of course, by Ohm's law, and the electromotive force depends upon the difference of temperature and also upon the materials. When large thermo-electric currents are

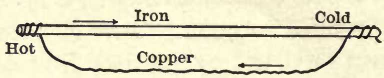


FIG. 402.—ELEMENTARY THERMOPILE.

desired, the different materials should be chosen with great care. Much experimenting has been done to discover the combinations that give the best results, and special alloys are used by manufacturers of thermo-piles. Iron and German silver are frequently used for experimental work, since they are easily obtained, and also give comparatively high electromotive force. Thermo-electric currents were observed by Johann Seebeck, a German physicist, in 1821.

403. *Are thermo-electric currents common?*

They are more common than is often suspected. They often make trouble with accurate electrical measurements, since it is frequently impossible to keep all parts of the apparatus at the same temperature; thermal currents are thus set up, which interfere with exact measurements. For example, in measuring resistance with the Wheatstone bridge, the currents heat the circuit slightly, and this inequality of temperature sets up thermal currents, which affect the galvanometer after the main current has been cut off, so that it is difficult to obtain an exact balance. Thermal currents are always of low electromotive force, being less than one-thousandth of a volt per junction, so that they are troublesome only in circuits of small resistance and with delicate instruments. It is suspected that electrolytic troubles are sometimes started by thermo-electric currents, although this seems not to have been verified.

404. *What is a thermopile?*

The thermopile is an apparatus for transforming heat energy into electrical energy. It is the thermo-couple developed by making a circuit of a number of pairs of metals or alloys so arranged that alternate junctions may be heated while the remaining junctions are kept at a lower temperature, somewhat as suggested in the figure. If the two conductors are iron and German silver, the heat causes

current to flow from the German silver to the iron at the hot junctions. Such currents are called "thermo-electric." The heat is generally supplied by one or more gas jets, although the largest sizes are made like stoves and are suitable for burning coal. The outer junctions are usually kept comparatively cool by means of extended

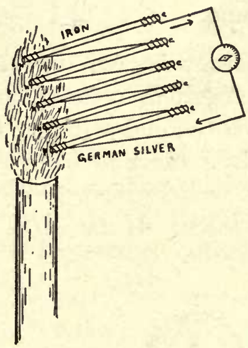


FIG. 404A.—THERMOPILE.

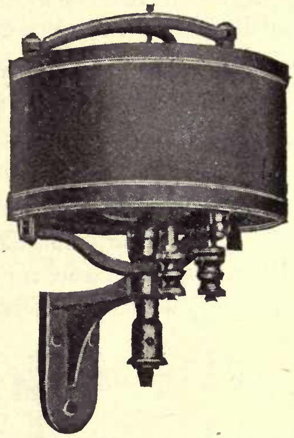


FIG. 404B.—COX THERMO-ELECTRIC GENERATOR.

plates, sometimes formed into tubes so as to assist the circulation of cooling air; in the Cox thermopile, which probably represents the highest development, the outer ends are cooled by the circulation of water in the jacket. A cylindrical Noe thermopile and a larger Gulcher apparatus are also shown in the accompanying figures.

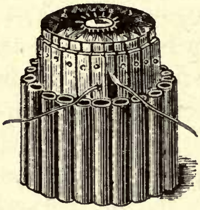


FIG. 404C.—NOE THERMOPILE.

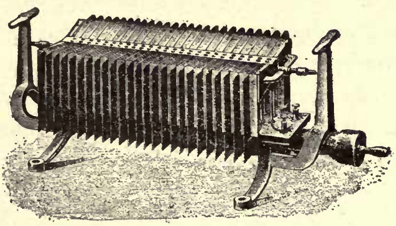


FIG. 404D.—GULCHER THERMOPILE.

405. *For what purposes are thermopiles used?*

They are used for obtaining currents where great steadiness is required, such as in chemical analysis. They are suitable for all purposes for which a closed circuit battery would be used, that is, when currents of uniform strength are desired for long periods. They are suitable for electro-plating, for operating telegraph lines, small

motors, fans, or for other purposes. Current from a thermopile is generally cheaper and less troublesome than when it must be obtained from a primary battery. Thermopiles are also used for measuring radiant energy and for measuring temperatures.

406. *Are thermopiles suitable for electric lighting?*

They have not been constructed in sufficiently large sizes, except for small lamps. They can not compete with engines and dynamos, both because of difficulty in making large sizes, and because of the greater efficiency of the engine and dynamo.

407. *How is a thermopile used for measuring radiant energy?*

Thermopiles for such work are arranged in rectangular form, somewhat as shown in the figure. When one end is exposed to any radiation, such as the sunlight or the heat radiated from a fire or lamp, that end absorbs heat and becomes warmer than the other end, the result being a thermo-electromotive force. If the wires leading

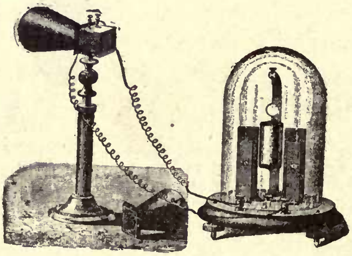


FIG. 407.—THERMOPILE AND GALVANOMETER.

from the thermopile are attached to a galvanometer, the electromotive force and current can be measured by comparing the amount of the thermal current obtained when the end of the thermopile is directed successively toward different sources of energy; the relative intensities of their radiations are indicated by the current through the galvanometer. (See Nos. 828 to 835.)

408. *How is a thermopile used for measuring temperature?*

Such use depends upon the fact that, within certain limits, the current in a thermal couple varies directly with the difference between the temperatures of the hot and cold junctions. After the apparatus has been properly calibrated by keeping one junction at a fixed temperature, while that of the other is heated to different known temperatures, the current produced being carefully noted at each step, the apparatus can be used to determine the temperature of any desired spot by placing one junction at that spot while the other is kept

at a standard or known temperature. The temperature at the spot desired can then be calculated from the current through the thermo-electric circuit. A modification is sometimes used when it is desired to keep two points at equal temperatures: one junction of a thermal-couple is placed at each of the two points, and if no current flows through the circuit, it indicates that the two junctions are at the same temperature. Zeleny thus detects heating of grain in elevators.

409. *Is the thermo-electric effect reversible?*

Peltier discovered in 1834 that a current through a junction of two metals would heat or cool it according to the direction of the current, heating being observed if the direction of the current was the same as that which would have been produced by cooling the junction, and the reverse. This "Peltier effect" acts something like a counter-electromotive force in the thermopile. Various attempts have been made to utilize the Peltier effect for artificial refrigeration, but such seem not to be commercially successful.

410. *Are there any methods for obtaining electricity from heat other than the thermopile and the engine and dynamo?*

There are quite a number of methods in which electricity may be obtained from heat energy. One general class depends upon the maintenance of a constant difference of temperature between different parts of the circuit. Another general class depends upon a changing temperature of the same part. The latter class includes two quite distinct methods which may be called "pyro-electric" and "pyro-magnetic."

411. *What are pyro-electric generators?*

Theophrastus (about 450 B. C.) described what he called an "electric stone" that had the power of attracting light substances when heated. Aside from atmospheric electricity, this seems to have been about the first knowledge of what we now know as static electricity. Certain stones and crystals become charged positively at one end and negatively at the other when heated, and then show the attractive and repellant effects of static electricity. The tourmaline takes its name from the Ceylonese word "tournamal," meaning "ash collector." The electrification is due to the change of temperature. No commercial use is made of such electrification, except possibly to increase the sale of certain stones.

412. *What are pyro-magnetic generators?*

These are devices based upon a discovery, made by Gilbert about 1600 A. D., that iron and other magnetic substances lose their mag-

netic properties when heated white hot. In 1868, Gore made use of this phenomenon for varying the magnetic flux through a coil and so inducing a current. This was further developed by Edison, Menges and Tesla, but none of them arrived at commercial success. The same phenomenon has been applied to the operation of small motors by Thomson and Houston, McGee, Schwedoff, Cooper, Berliner, Edison and Menges.

413. *Has heat been used in connection with chemical action for developing electricity?*

This has been tried by a number of people. In 1881, Kendall obtained currents from platinum plates heated to redness in hydrogen and other gases, and with melted salts or glass, getting about one-half volt per cell. Following some experiments of Becquerel in 1855, Jablochkoff in 1877, and Brard in 1882, constructed what they called "electro-generative slabs," composed of carbon, nitrate of potash and copper, which produced electricity by their own combustion when thrown into a fire. In 1886, Case announced a kind of cell based upon the fact that chromic chloride dissolves metallic tin when heated to the boiling point, and precipitates it when cooled; this cell developed an electromotive force of 0.26 volts. In 1883, Acheson developed 2.25 volts by heating manganese binoxide between two concentric cylinders. In 1887, Ettinghauser and Nernst obtained an E.M.F. of 0.00125 volts by sending heat through a conductor in a strong magnetic field, apparently converting some of the heat into electricity. In 1886 to 1889, Acheson worked along this line and devised a number of plans for changing electricity into heat in the influence of a magnetic field. In 1896, Jacques brought out a cell in which current was obtained by heating iron and carbon electrodes with caustic soda.

414. *Is the heating effect of the electric current of much practical importance?*

The heating effect must be taken into account in the design, construction and operation of almost all electrical apparatus, to prevent excessive rise of temperature. On the other hand, the heating effect is desired for many purposes, for it is the basis of many useful applications of electricity.

415. *What governs the amount of heat from a current?*

It varies both with the current and with the resistance. No substance is known that has perfect conductivity, that is, every conductor has more or less resistance. (See Nos. 338 to 354). The passage of current through resistance causes a certain fall of potential or

voltage, which, by Ohm's law, equals the product of current by resistance. The product of current by this drop represents the power lost or changed from electricity into heat, and may be expressed in an equation,

$$W = I \times E = I \times I \times R = I^2R.$$

The product of current by drop, or of current squared by resistance, when multiplied by the time during which the current passes, represents the amount of heat developed. The unit of heat may be taken as the joule, which equals the heat developed by 1 watt acting for one second; or it may be taken as the calorie, which equals the amount of heat necessary to raise the temperature of 1 gram of water 1 deg C., and equals 4.2 joules, or 4.2 volt-ampere-seconds, or 4.2 watt-seconds. (See Nos. 213, 220 and 221.) The number of calories may thus be expressed by the equation,

$$\begin{aligned}\text{Calories} &= \frac{\text{watts} \times \text{seconds}}{4.2} = 0.238 \times \text{watts} \times \text{seconds}\\ &= 0.238 \times \text{current} \times \text{drop} \times \text{time}\\ &= 0.238 \times \text{current} \times \text{current} \times \text{resistance} \times \text{time}\\ &= 0.238 \times I \times E \times T\\ &= 0.238 \times I \times I \times R \times T.\end{aligned}$$

416. *What are some of the ways in which the heating effect may be avoided or made small?*

Conductors for carrying current must be sufficiently large, or there will be not only an excessive loss on the line, but the temperature of the conductors will be liable to rise so high as to endanger the insulation or even to set fire to surrounding substances. For this reason the insurance companies and the electrical interests have made a careful study of the conditions under which electricity may cause fire risks, and have adopted sets of rules governing both the size of wire that must be used for certain currents and also the manner of placing and insulating the conductors. Copies of the "National Electrical Code" may be had on application to any city or state Board of Underwriters.

417. *How is the safe carrying capacity of a conductor determined?*

For "wiring" purposes, that is, for use as conductors for electric light or power, the tables of the National Electrical Code apply. The size of wire needed in other situations depends so largely upon circumstances that no definite rule can be laid down. The rule in the United States Navy is 1000 amp. per square inch, equivalent to 1273 circ. mils per ampere. The moving parts of dynamos and motors

have the copper wire proportioned for about 350 to 700 circ. mils per ampere, while the stationery coils have 850 to 1400 circ. mils per ampere. The time in use, ventilation and allowable rise of temperature vary so widely that no definite general rule can be laid down.

418. *What is the rule of the National Electrical Code relating to currents and sizes of wire?*

Conductors must be made of practically pure copper, or if of other material, must be made enough larger to secure equal conductivity. No wire must carry more than the current indicated in the following table (see also table on page 76):

TABLE OF CARRYING CAPACITY OF COPPER WIRES

B. & S. G.	Circular Mils	Weather-proof Wires. Amperes	Rubber-Covered Wires. Amperes	Circular Mils	Rubber-Covered Wires. Amperes	Weather-proof Wires. Amperes
18	1,624	5	3	200,000	200	300
16	2,583	8	6	300,000	270	400
14	4,107	16	12	400,000	330	500
12	6,530	23	17	500,000	390	590
10	10,380	32	24	600,000	450	680
8	16,510	46	33	700,000	500	760
6	26,250	65	46	800,000	550	840
5	33,100	77	54	900,000	600	920
4	41,740	92	65	1,000,000	650	1,000
3	52,630	110	76	1,100,000	690	1,080
2	66,370	131	90	1,200,000	730	1,150
1	83,690	156	107	1,300,000	770	1,220
0	105,500	185	127	1,400,000	810	1,290
00	133,100	220	150	1,500,000	850	1,360
000	167,800	262	177	1,600,000	890	1,430
0000	211,600	312	210	1,700,000	930	1,490
				1,800,000	970	1,550
				1,900,000	1,010	1,610
				2,000,000	1,050	1,670

The lower limit is specified for rubber-covered wires, to prevent decentering of the wire and deterioration of the insulation by the heat but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above tables. The carrying capacity of sixteen and eighteen wire is given, but no smaller than fourteen is to be used, except in pendants and in fixtures. The choice between weatherproof and rubber-covered wires depends upon circumstances. As a general rule, rubber-covered wire is required for use inside of buildings.

419. *What governs the rise of temperature in a conductor carrying a current?*

Whenever current passes through a conductor, more or less electrical energy is unavoidably changed into heat energy (see No. 415), and the temperature rises until the heat lost by the conductor equals that received from the current.

420. *What becomes of the heat liberated in a conductor?*

It is carried away by conduction, by convection and by radiation. Some of it is carried away by conduction along the wire to places where the temperature may be lower. Some of it is carried away by convection currents of air. Some is carried away by radiation, a process similar to that by which one feels the direct heat from a fire or from the sun. The amount carried off by convection and by radiation depends upon the difference between the temperature of the conductor and that of the surrounding objects, upon the character of the surface of the conductor, and upon the freedom of circulation of air.

421. *How can excessive heating of conductors be avoided?*

By proper design in the first place, making the conductors amply large for the current to be carried. In the next place, there should be in each circuit suitable safety devices, such as fuses or circuit breakers, that will open the circuit when the current exceeds a safe amount.

422. *What is a circuit breaker?*

A circuit breaker is an electromagnetic device for opening an electric circuit when the current varies beyond certain desired limits. Generally it is designed to open the circuit when the current exceeds a certain amount, although for some purposes it is arranged to open

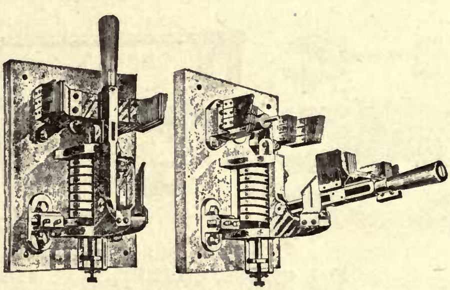


FIG. 422.—CIRCUIT BREAKER.

the circuit when the current falls below a fixed amount. It is operated by an electromagnet whose core is attracted so as to trip a release

trigger or detent, and allow a spring to throw open the switch when the current exceeds the limit set. Circuit breakers are frequently used instead of, or to supplement, fuses with dynamos and motors.

423. *What is a fuse?*

There are two entirely different devices called by the same name and based upon the heating effect of the current, one being used for firing explosives. The safety fuse referred to in connection with insurance rules is a special part of an electric circuit, designed to carry the ordinary amount of current, but to melt and open the circuit in case the current becomes great enough to heat any other part of the circuit beyond a safe temperature. The fuse is made of such material and dimensions that its resistance is considerably higher than an equal length of the rest of the circuit. Since the heat developed equals the product of the resistance by the square of the current, the fuse is continually at a higher temperature than other parts of the circuit (except, of course, lamps and other heating devices); as its melting temperature is generally comparatively low, an increase of current above that for which the circuit is designed will raise the fuse to its melting temperature, so that it will fall away and open the circuit.

424. *What other names are given to fuses?*

They are called cut-outs, safety catches, safety fuses, safeties, fuse plugs. The fusible part is sometimes called a fuse link, a fuse plug, a cartridge, a protector or sometimes a fusible.

425. *What are the requirements of a fuse?*

It should melt at a comparatively low temperature, so as not to endanger setting fire to surrounding substances. It should melt quietly, so as not to throw melted particles where they might cause damage.

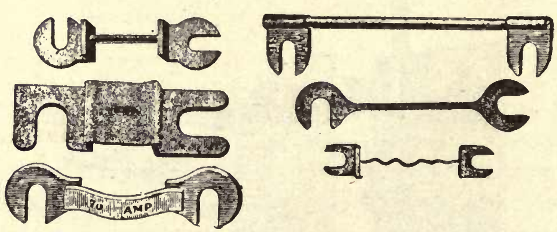


FIG. 425.—FUSE LINKS.

It should have hard terminals, so that the contact between it and the rest of the circuit shall continue firm. It should have a definite melting point that will not change with prolonged heating. It should be

long enough so that an arc cannot be maintained between the terminals after the fuse is melted. It should be mounted upon a non-combustible, non-absorptive base. See Nat. El. Code rules, 52, 53.

426. *What substances are used for fuses?*

The most common is an alloy of tin and lead, such as "half and half" solder. Bismuth is frequently added to the alloy to lower the melting point. Copper wire is sometimes used in exposed places where there is no danger from flying particles or from the high temperature of the fuse with normal current. Iron wire should not be

FIG. 426.—FUSE WIRE.

used, since it burns when melted and is very liable to carry fire. Numerous "tested" fuses of more or less secret alloys are upon the market. Aluminum is coming into extensive use as a fuse metal.

427. *What determines the current required to melt a fuse?*

It depends upon the diameter, more current being required to melt a thick wire than a thin one; it depends upon the melting temperature of the material, some alloys melting at low temperatures; it depends upon the specific resistance of the fuse metal, also upon its temperature coefficient (that is, the amount the resistance changes with temperature), since the resistance determines the amount of heat developed by the passage of a given current; it depends upon the cooling effect of the terminals, and, therefore (within certain limits), upon the length of the fuse wire; it depends upon the conditions for dissipating heat by convection and radiation. The quickness with which a fuse will melt after the current has reached the limit depends upon the specific heat of the metal, that is, upon the number of heat units required to raise the temperature 1 deg., and

also depends upon the latent heat, or the amount of heat that disappears in melting the substance. The current required to "blow" a fuse varies to some extent with age, as the fuse generally stands at a comparatively high temperature whenever the normal current is passing, and hence is liable to oxidize more or less; molecular changes also occur in alloys maintained at a high temperature, so that the melting temperature is liable to change.

428. *How are fuses rated?*

Fuses are sometimes rated according to the number of amperes to be taken normally by the circuit they are to protect. For example, a 10-amp. fuse is supposed to protect a circuit whose regular current should not exceed 10 amp., and to open the circuit if the current rises above say 12 amp. It is also common to rate fuses according to the current they will certainly carry, for example, a 10-amp. fuse wire will carry 10 amp. without melting, but how much more it will carry is not specified, and it may carry even 20 amp. before melting. The rules of the underwriters require that each fuse be stamped with about 80 per cent of the maximum current it can carry indefinitely, thus allowing about 25 per cent overload before the fuse melts.

429. *Does a fuse wire always melt with the same current?*

The fusing current is liable to vary 50 or even 100 per cent, according to circumstances. The temperature of the surrounding air or other substances affects the melting current greatly, for the melting temperature is about constant, while the rate at which heat from the fuse will be transferred to the surroundings depends upon the difference of temperance between them and the fuse; consequently, a fuse in a warm place will be melted by a smaller current than a similar fuse in a cold place. For a similar reason, a fuse in an inclosed place, where there is little chance for the heat to be dissipated, will melt with a smaller current than the same in an open place. If the current increases gradually to that which would ordinarily melt the fuse, the high temperature makes the fuse wire oxidize rapidly; this sometimes makes a sort of tube of oxide which will not break even after the fuse wire inside has melted, and so the fuse carries more than its rated current. The fuse wire is generally made of soft material, such as lead or solder, and the alternate heating and cooling causes the fuse metal to flatten and spread under the fastenings, so that the contact becomes poor; this causes an increased amount of heating, which causes the fuse to melt at a lower current than intended. To prevent such loosening, it is advised that fuses be soldered to hard copper terminals. Open fuses are so unreliable that circuit breakers

are preferred for large currents, and inclosed or "protected" fuses generally called "cartridge fuses" are preferred in most cases.

430. *How much current is required to melt a wire?* When the wires are open to the air and when long enough so that the cooling effect of the terminals does not extend to near the middle of the wires (the fuse wires being from 2 ins. to 12 ins. in length, according to their diameters), the currents required for melting are approximately as indicated in the following table for copper, lead and solder wires:

TABLE OF FUSING CURRENTS.

B. & S. Gage No.	Diameter in Inches	Fusing Current in Amperes		
		Copper	Lead	½ Lead and ½ Tin
36	.005	4	....	....
34	.006	5	....	....
32	.008	8	1	1
30	.010	11	....	....
28	.013	14	2	2
26	.016	20	3	....
24	.020	30	4	3
22	.025	42	7	5
20	.032	60	10	7
19	.036	70	11	9
18	.040	83	13	11
17	.045	100	15	13
16	.051	120	17	15
15	.057	140	20	18
14	.064	166	22	20
13	.072	200	27	24
12	.081	235	33	30
11	.091	280	38	35
10	.101	335	44	41
9	.114	390	51	48
8	.129	450	62	58
7	.144	520	77	73

The above figures are calculated from a law discovered by Preece, that the diameter (in inches) of a copper wire equals the cube root of the square of the quotient of amperes divided by 10,244. For lead, the divisor is 1379. For the half and half solder, lead and tin, the divisor is 1318. The figures for lead and for solder agree closely with results of experiments by Bathurst. Part of the figures for copper fuses have been tested experimentally and found closely correct.

431. *Will two fuses in multiple carry twice as much current as one?*

They will if each carries the same current, and if the two are so placed that neither affects the heating of the other. Two fuses twisted together or placed close together will carry less than twice the current of one, since the heat from the two is not carried off so easily as from one. If one fuse has more resistance than the other, as might occur when two fuses of the same stock but of different lengths are coupled in multiple, the one having the smaller resistance will carry more than its half of the current, and, consequently, will melt before the total current is twice the melting current for one fuse.

432. *How can a multiple fuse be adjusted to carry any desired current?*

If the fuses are placed so that the heat from one does not affect the other, as when the two are placed in separate blocks, their joint carrying capacity may be adjusted approximately by the following method: Suppose it is desired to make a fuse for 350 amp. from a No. 12 bare copper wire which fuses at about 235 amp. Use two fuses of such length (that is, of such relative resistance), that when one carries 253 amp., the other will carry the difference between 235 and 350, the total current, or 115 amp. This may be done by making one fuse, say 2.35 ins. long, and the other 1.15 in. The shorter one will then carry $\frac{235}{350}$ of the total current, while the longer one carries $\frac{115}{350}$. It would be better to double these lengths so that the flash at melting can not maintain an arc across between the terminals.

433. *What is a fuse block?*

A fuse block is a device for holding a fuse. It usually consists of brass clamps mounted on porcelain. Generally a cover is provided, both for the purpose of preventing the fuse from flying when melting, or "blowing," and also to improve its looks, and to reduce the amount of "live" surface exposed to accidental contact. Fuse blocks are made in many different styles and for many different situations. For use on high potential circuits, such as 1000-volt or higher pressure circuits (and often for 100-volt circuits), the fuse is commonly placed on a separate cover piece, so that the fuse wire can be clamped in place on the cover before being connected with the live wires. (See also No. 437.)

434. *What are the principal kinds of fuse blocks?*

There is a great variety to suit various purposes. For use in electric light and power circuits, fuse blocks or "cut-outs" may be classi-

fied into "main line cut-outs" and "branch blocks." A branch block is used for connecting branches to a larger circuit, the fuses being so arranged that, if trouble occurs on the branch, it is cut off without

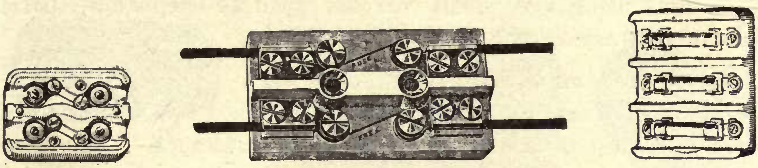


FIG. 434A.—MAIN LINE CUT-OUTS.

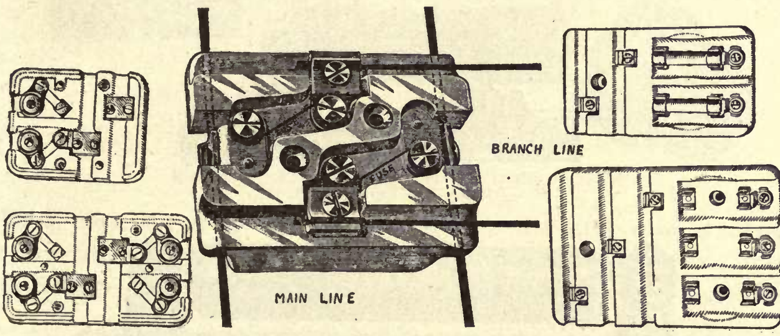


FIG. 434B.—BRANCH BLOCKS.

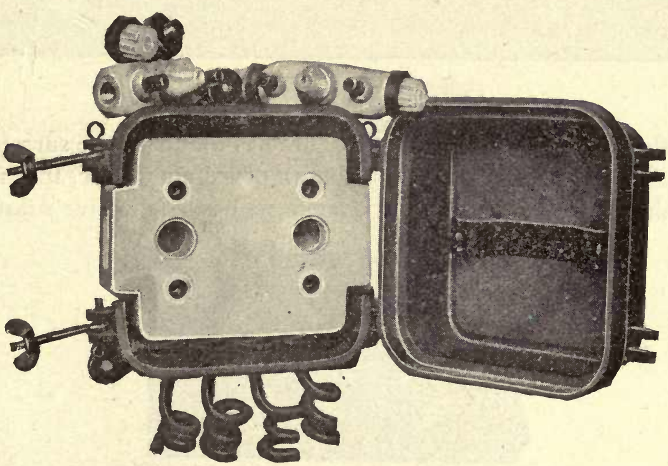


FIG. 434C.—FUSE BLOCK FOR TRANSFORMER.

opening the main line. As its name indicates, a main line cut-out is placed in the main line. The accompanying figures show common

forms of main and branch blocks for use on circuits for electric light or power inside buildings. Fuse blocks for use out of doors are made weatherproof, being encased in cast-iron boxes, somewhat as shown in the accompanying illustration of inclosed fuse for transformers. For circuits using very small currents, such as telephones, special forms of fuse are employed.

435. *What is an inclosed fuse?*

In an inclosed fuse the fusible wire is placed in a tube or in a cavity within porcelain or some other insulating substance. The space around the fuse wire is sometimes filled with some substance that will prevent the formation of an arc after the melting of the fuse. One

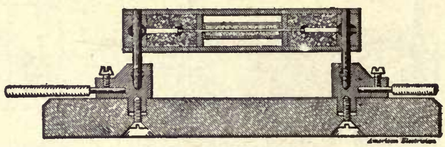


FIG. 435A.—INCLOSED FUSE.

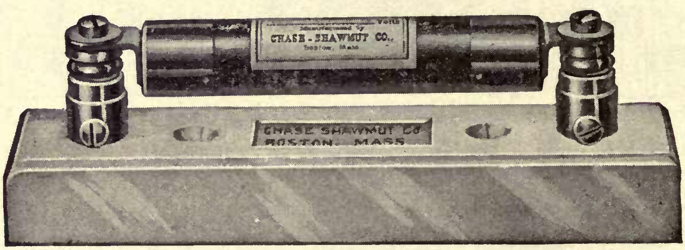


FIG. 435B.—INCLOSED FUSE.

style shown in the accompanying figure has the fuse wire surrounded by a chemical substance, such as borax or sal ammoniac, that unites with the lead fuse wire, and by forming a non-conductive substance,

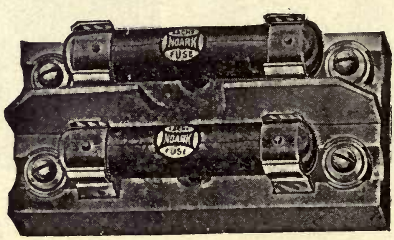


FIG. 435C.—INCLOSED FUSE WITH INDICATOR.

destroys the conductivity of the fuse in case its temperature rises above a specified degree. Sometimes a fine fuse is placed outside the

tube so as to melt after the main fuse inside, and thus indicate whether it has melted. In others, such as the Edison fuse plug, the fuse wire is encased in a glass or porcelain cup, from which air drafts are excluded by the cover. Inclosed fuses are more re-

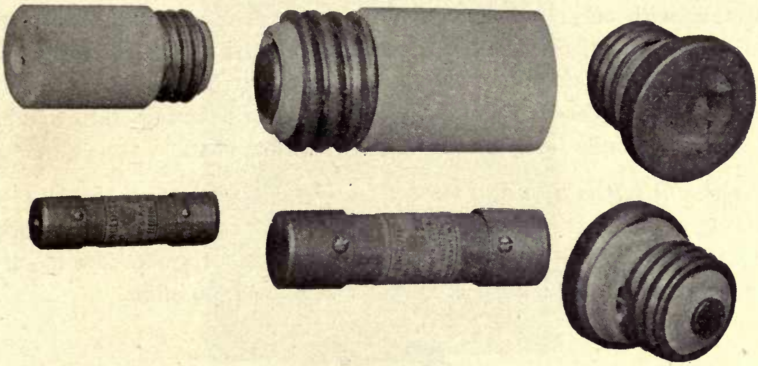


FIG. 435D.—FUSE PLUGS, 125 AND 250 VOLTS.

liable than the older open fuses, because the fuse wire is under practically the same conditions at all times, and will, therefore, melt at a more definite temperature. They are now generally required.

436. *What is a detachable fuse?*

The fuse terminals of a detachable fuse block are attached to the cover piece, that is, to a piece which may be removed from the stationary block, so that the fusible portion may be placed in the cover

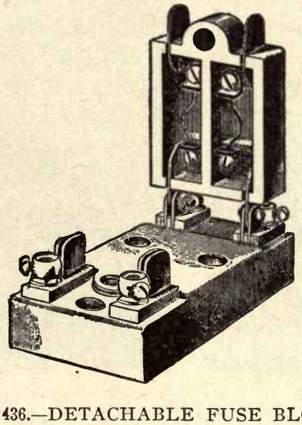


FIG. 436.—DETACHABLE FUSE BLOCK.

or "pocket" while entirely disconnected from the circuit, the connections being made when the cover is placed in position on the base.

437. *What is a protected fuse?*

Some manufacturers make fuse blocks in which the fuse is enclosed in a porcelain tube or channel, having a small aperture through which the vapors following the melting fuse can escape, the arc being blown out. The tube protects the fuse from air drafts and from contact with other substances, and also fixes it at a definite length. In the protected fuses the fuse wire is generally in a piece separate from the rest of the block, so that the fuse may be renewed while the cover or plug piece is entirely detached from the circuit, thus making it safer to handle than the ordinary open fuse block.

438. *What is a "bug" cut-out?*

Bug cut-outs are small single pole cut-outs for placing in cramped and awkward places, such as in fixtures, where a regular fuse block is impracticable. Their use is avoided whenever possible.

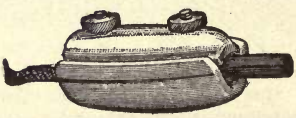


FIG. 438.—BUG CUT-OUT.

439. *What is the difference between single-pole and double-pole cut-outs?*

Cut-outs are generally made double-pole, that is, so that there is a fuse on each side of the circuit to give protection against heavy currents, whether caused by a "short-circuit" on the line itself, or caused by two ground connections in different parts of the circuit. In the case of large currents at high potentials, it is common to use two

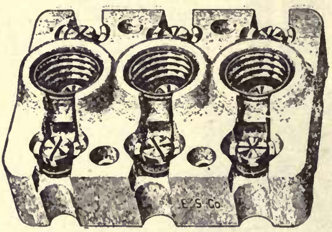


FIG. 439A.—THREE-WIRE MAIN CUT-OUT.

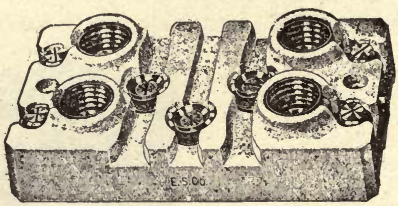


FIG. 439B.—THREE-WIRE BRANCH BLOCK.

single-pole cut-outs, in order to maintain a safe distance between the two sides of the circuit. Three-wire systems require a fuse in each of the three wires at each branch.

440. *What are panel boards or panel cutouts?*
In wiring buildings it is common to use the "cabinet system," in

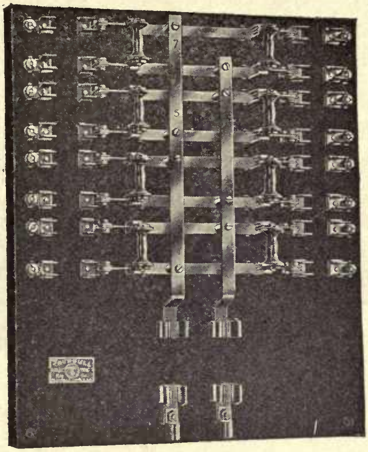


FIG. 440A.—DISTRIBUTION PANEL, CARTRIDGE FUSES.

which the lamp circuits radiate from one or more distribution centers where the fuses (and sometimes the switches) are collected for

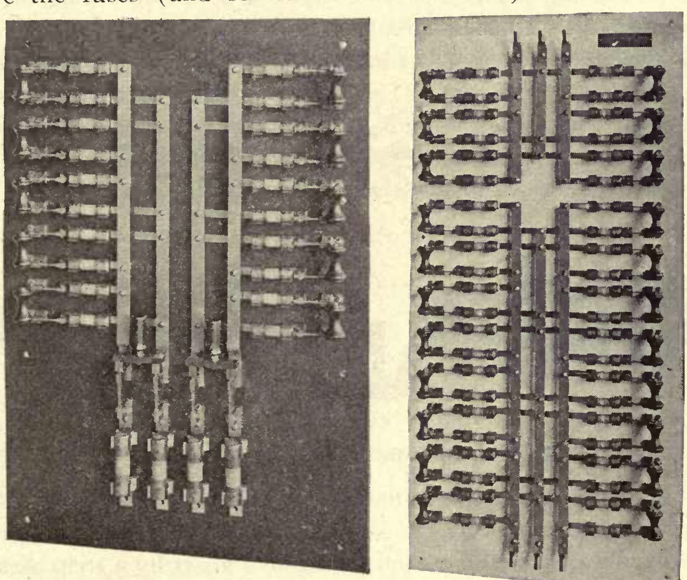


FIG. 440B.—CABINET PANELS, PLUG FUSES.

greater safety and convenience. When the fittings are mounted directly on a slate or marble slab, it is called a panel board, fuse

panel or tablet; when they are mounted on separate porcelain bases which are then mounted on asbestos-covered wood or on iron, it is called a panel cutout. The tablets should be enclosed in cabinets of non-combustible, non-absorptive material such as slate, marble, steel, or wood protected by asbestos or slate.

441. *What kind of fuse is used on telephone and similar lines?*
The currents ordinarily used on such lines are so small that foreign currents of less than one ampere may cause damage. The fuses

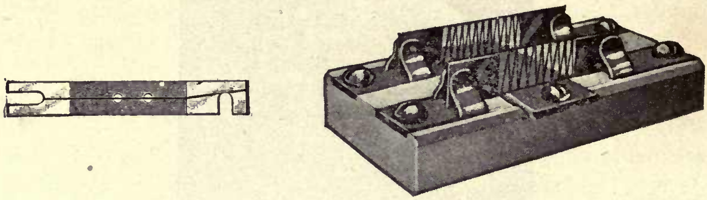


FIG. 441A.—TELEPHONE FUSES.

must therefore be much more sensitive than those used on electric light circuits. A common form is a piece of fine fuse wire mounted on a strip of mica with copper terminals. The "grasshopper" fuse has some fine high-resistance wire doubled up inside a plug of wax and connected by a bell-shaped shell and a stiff-wire hook to a fork and a spring; an excessive current will soften the wax, when the spring breaks the fine wire. The McBerty "thermal arrester" used by the Bell companies contains a rubber cylinder, B, in which are a number of turns of fine high-resistance wire in which a stray current will generate so much heat as to melt the special solder and

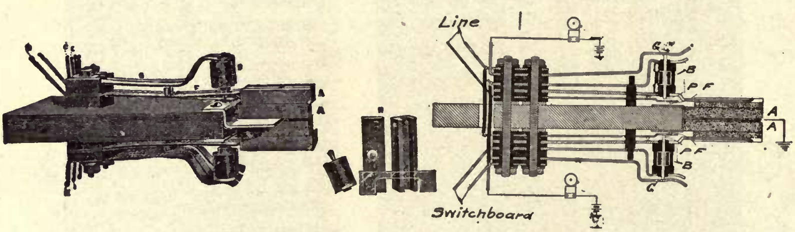


FIG. 441B.—THERMAL ARRESTERS.

allow a spring, G, to push the central pin, P, against a smaller spring, F, which connects the line with the earth; A is a lightning arrester with a couple of carbon pieces held apart by a strip of mica (see No. 156); sometimes a plug of fusible metal is placed in one carbon so as to melt and make a firm connection in case the lightning discharge is accompanied by considerable current; sometimes auxiliary strips are added so as to ring a bell whenever a fuse goes out.

442. *What is meant by a telephone protector?*

A telephone protector is a combined fuse and lightning arrester. The arrester usually consists of pieces of flat carbon separated by thin pieces of mica notched or perforated so as to leave thin air

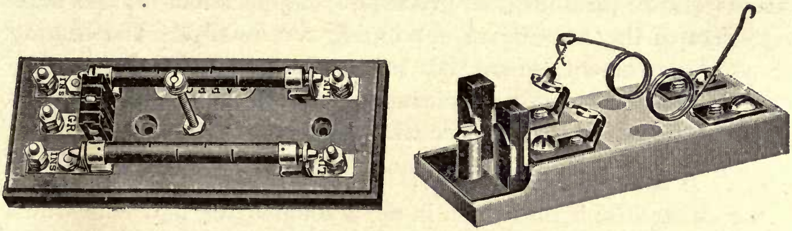


FIG. 442.—TELEPHONE PROTECTORS.

spaces between the carbon blocks. The fuse may be of a type to melt and open the circuit, or it may simply connect the line to the earth, as explained in No. 441.

443. *Are fuse wires adaptable for fire alarms?*

Fusible metal has been applied in several ways to the extinguishing of fires by opening sprinklers when the temperature exceeds a definite degree. The same idea has been applied in the "montauk" cable

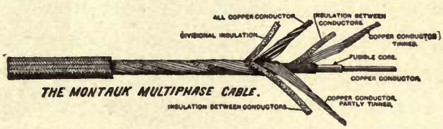


FIG. 443.—FIRE DETECTOR CABLE.

for giving an alarm under similar circumstances. The cable consists of a number of conductors, the inner one of which is surrounded by an alloy that fuses at about 370 deg. F. If the cable is exposed to a high temperature, such as might be caused by an incipient fire, the fusible alloy melts and completes the circuit between the central wire and those near it, thus sending in an alarm through an electric bell or similar device.

444. *For what useful purposes is the heating effect of the current employed?*

The heating effect is used in safety devices such as the fuses noted above. (See Nos. 423 to 443.) Moderate degrees of temperature are used in heaters of various sorts, such as stoves, heating pads, tea kettles, coffee pots, ovens, smoothing irons, curling iron heaters,

soldering coppers, solder or babbitt melting pots, glue pots, branding irons, stamp cancellers, surgeons' cauteries and the like. Higher temperatures are used in the tempering of steel, in blasting fuses, in incandescent lamps, arc lamps, electric welding and forging, and in various electro-metallurgical processes. Applications of the heating effect of the current are developing continually. The heating effect of the current is used to a small extent in electrical measurements. Heat is developed incidentally in connection with rheostats for regulating or absorbing electrical energy.

445. *What is a blasting fuse?*

A blasting fuse is illustrated in the accompanying figure, in which a small platinum wire, *E,* may be heated by a current and so ignite an explosive mixture, *B,* which will ignite a still larger charge outside the fuse. Current enters and leaves through the wires, *C,* which

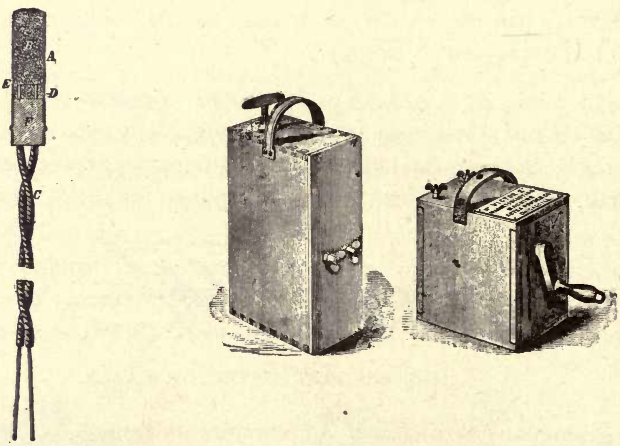


FIG. 445.—BLASTING FUSE AND MAGNETOS.

are long enough to extend beyond the surface of the hole. As many as forty of these fuses may be connected in series and fired simultaneously. Current is usually furnished by a small magneto dynamo similar to, but more powerful than, those used for ringing telephone bells.

446. *What is a rheostat?*

A rheostat is a conductor arranged to dissipate electrical energy into heat. It may be used simply to regulate the resistance of the circuit of which it is a part, it may be to regulate the current by changing the resistance of a circuit, it may be to dissipate energy as in a test, it may be to develop desirable heat from electricity. Usually the rheostat is so arranged that its resistance may be changed at will.

447. *For what purposes are rheostats used?*

Rheostats are connected into the field magnetizing circuits of dynamos to regulate the electromotive force of the dynamo; they are used in series with motors to make them start slowly; they are sometimes used in the field circuits of motors to regulate the speed; they are sometimes used to absorb the power of a dynamo while being tested for capacity and efficiency; they are used to regulate the current in a great variety of apparatus supplied from circuits of constant potential. Rheostats are sometimes used to vary the difference of potential between the terminals of apparatus connected to constant potential circuits.

448. *Of what material are the conductors in rheostats composed?*

Metallic wire is most common, although carbon and graphite are used sometimes; it is not unusual to employ water, made conducting by the addition of salt or acid. Iron is cheap and will stand a high temperature. Copper has high conductivity, and is convenient where large currents at low voltage must be controlled. German silver has high resistance and low temperature coefficient, and is used where the resistance must be constant. Other alloys are used.

449. *How are the conductors supported in rheostats?*

Where the energy is small, as in telegraph systems and in standard resistances in Wheatstone bridges and similar laboratory apparatus, the wire may be wound in coils directly upon wooden spools. Where there is liable to be considerable heat, the conductors must be supported on non-combustible material, as is required by the insurance rules covering the use of electricity for lighting and power purposes. The conductors may dissipate their heat into the open air directly or through another surrounding medium, such as enamel, which carries

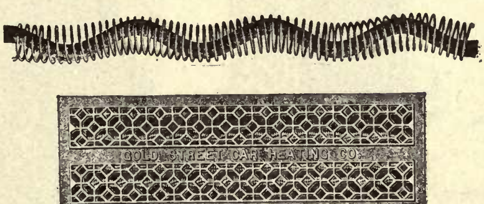


FIG. 449A.—ELECTRIC AIR HEATER.

the heat to cast-iron base plates. The conductors may be wound on slate slabs, on a framework of iron rods insulated with asbestos, or on insulated metallic spools with layers of asbestos between the layers of wire; the wire may be wound into coils which are stretched be-

tween insulators on a frame of iron or of insulating material. When the rheostat is to be used for only a short time, the wire is sometimes wound on spools, as such method allows a large amount of wire in small space, and the capacity of such a rheostat depends more on its capacity for taking up heat than on radiation and convection. When spiral coils are employed, provision is made for free circulation of

FIG. 449B.—SECTION OF ENAMEL RHEOSTAT.

air. Sometimes asbestos tubes are placed inside coils of small wire for the purpose of keeping them stiff, while the convolutions are close together. In some cases the resistance wire in small rheostats is wound on flat "cards" of mica or fuller board, which are then bent and packed closely together. Absorption rheostats are sometimes immersed in water to facilitate cooling and thereby to increase their current carrying capacity. Cast-iron grids stand hard service.

450. *How is the resistance of a rheostat varied?*

The conductors are generally all in series, and connections are made at various points with contact blocks upon which a moving arm sweeps, so as to include more or less of the resistance, as suggested in the figure. Sometimes the resistance is reduced while the carrying

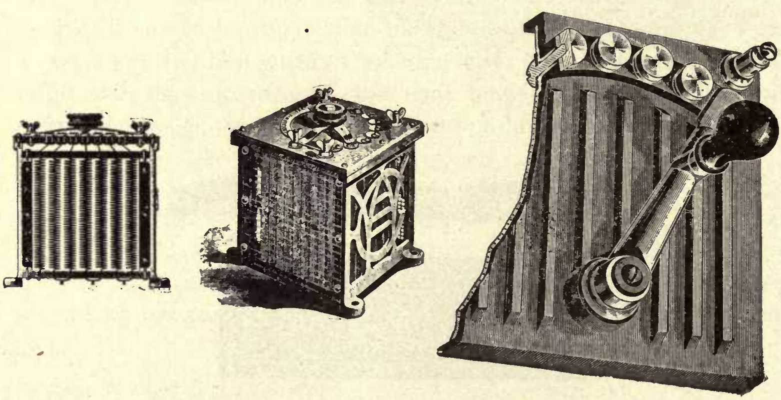


FIG. 450.—ADJUSTABLE RHEOSTATS.

capacity is increased by putting more or less resistance units in multiple, as when a bank of incandescent lamps is used for regulating a current. Combinations of the two are made occasionally, the highest resistance being given by connecting the units in series, while the

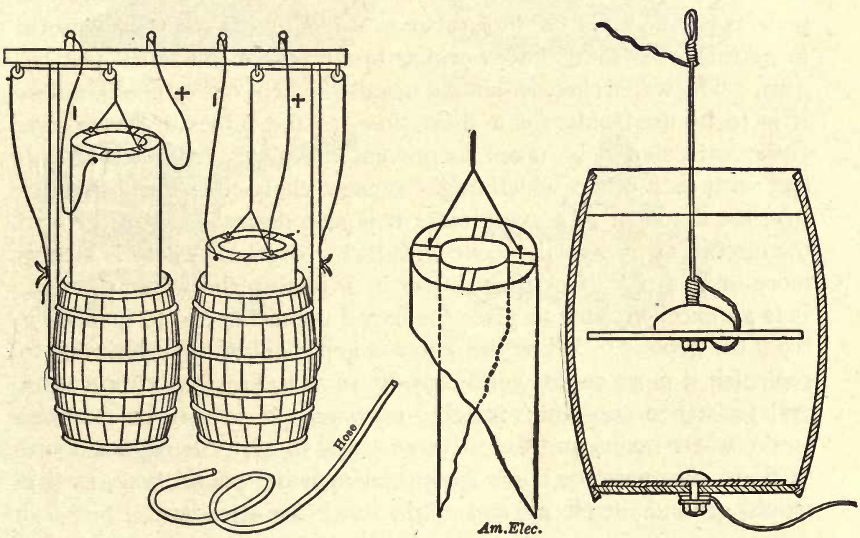
resistance is reduced by cutting out one section after another, the resistance being still further reduced by putting the units in multiple.

451. *How is a water rheostat constructed?*

The water may be contained in almost anything convenient, although it is generally safer to use a vessel of insulating material, such as a wooden box or barrel. The electrolyte may be ordinary water when pressures of 500 volts or higher are to be used. It is customary, however, to improve the conductivity of the water by the addition of a little salt or washing soda, or a little acid of some kind. A tablespoonful of salt is about enough for a barrel of water when the voltage is 550. More salt should be used for lower voltages. The conductor terminals are usually plates of iron although almost anything will do. The resistance is regulated by changing the distance between the plates, or the amount of surface of the plates, or by changing the density of the solution, the latter not being easily changed. Rectangular boxes of wood or stone are often used.

452. *How are the plates of a water rheostat made?*

Two pieces of iron pipe may be held apart by two boards and let down into the barrel; or one may be fastened to the side of the barrel and the other be adjustable up and down. The plates may



FIGS. 452A, 452B AND 452C.—WATER RHEOSTATS.

be two tubes or pieces of sheet iron held apart by wooden strips and adjustable up and down by ropes over pulleys, as suggested in Fig. *a*. When a close adjustment for small currents is desired, the plates

may be cut off spirally, as suggested in Fig. *b*. A convenient plan is to bolt a plate to the bottom of the barrel, being careful to make a tight fit and to paint the lower side well with pitch or asphalt; the upper plate may be a hitching weight to which is screwed a plate with a larger surface, the whole being suspended by the conductor, as suggested in Fig. *c*.

453. *How much energy may be dissipated in a water rheostat?*
A barrel containing fifty to sixty gallons will dissipate an equal number of kilowatts. Smaller rheostats sometimes take care of 20 to 150 watts per cubic inch of liquid. The allowable current varies from .25 to 3 amp. per square inch of surface on the exposed face of one electrode.

454. *What precautions are desirable in handling water rheostats?*
The water should not contain too much salt at first, since the resistance decreases as the temperature rises, and too much current is liable to be the result. The salt should be added from a solution, since it takes some time to dissolve and diffuse through the whole body of water; hence the resistance would continue to change for some time after the salt was added. The resistance is most steady when the water is boiling quietly; it takes quite a time before this point is reached, but the time taken to warm up the rheostat is useful in getting everything into working order before the actual test begins. The water rheostat should usually be kept out of doors, unless it is to be used only for a short time, as the fumes are corrosive. Great care should be taken to prevent the plates from actual contact with each other, which might cause a short-circuit and thus injure the dynamo. In many cases it is also desirable not to ground the circuit, as may easily occur with leaky barrels. There is always more or less risk of getting shocks in adjusting the water rheostat. It is an excellent plan to place the barrel upon timbers, to insulate it from the ground. When the water is kept boiling, it is desirable to replenish it more or less continuously, so as to keep the temperature and resistance constant; for this purpose a hose may be attached to the water mains and the valve adjusted to give the right amount of flow; care must be taken against using wire wound hose, as this would ground the circuit and might shock the attendant.

455. *How are electric heating and cooking utensils made?*
These generally have conductors of iron or of high resistance alloy wound upon asbestos or mica or imbedded in enamel on cast iron. The heat from the wire travels through the mica, asbestos or

enamel to the surrounding case, which may be a soldering copper, a flat iron, a cooking utensil or any other desired receiver.

FIG. 455.—CURLING IRON HEATER.

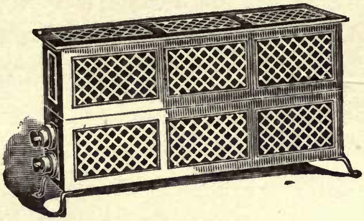


FIG. 455.—AIR HEATER.

456. *How much energy is required by electric heating devices?* Referring to 110-volt circuits, a $6\frac{1}{2}$-lb. sad iron for common household use requires 4 amp., or for laundry use, where the work is rushed, 5 or 6 amp.; a polishing iron requires 2.5 amp., and an 18-lb.

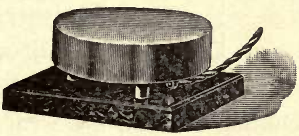


FIG. 456A.—DISC HEATER.

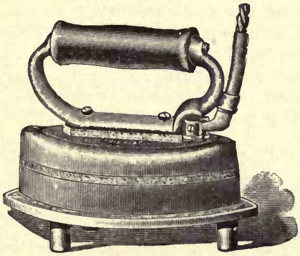


FIG. 456B.—LAUNDRY IRON.

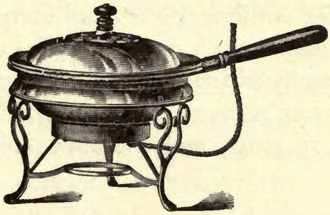


FIG. 456C.—CHAFING DISH.

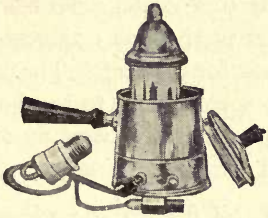


FIG. 456D.—BOTTLE WARMER.

goose iron, 5 amp.; a $4\frac{1}{2}$-in.-plate stove requires 1.9 amp., which current will make it hot in about two minutes. A larger disc heater, 6 ins. in diameter, requires 5.5 amp.; a single griddle requires the same current, and a three-section griddle requires 6 amp.; a chafing dish will take 4 amp. and small tea kettles require from 4 amp. to 7 amp.; an immersion coil for cooking food, boiling water and for heating water for special work takes from 4 amp. to 8 amp, according to size; a heating pad for application to the body uses only .4 amp., which is the same current required for a curling iron. Solder-

ing irons take 1 amp. to 2 amp., according to size. The above currents are taken by heating devices on 110-volt circuits. For other voltage the resistances are proportioned to absorb an equivalent amount of energy. (See Nos. 213 and 218.)

457. *How much does it cost to cook by electricity?*
The accompanying table gives the reported cost of cooking a luncheon for four or six persons, current being supplied at a cost of 3.75 cents per kw-hour, an unusually low rate.

COST OF COOKING BY ELECTRICITY.

	Amp. Current	Minutes	Cost
Cooking 3 pounds of beef........	8.7	20	1.186 cents.
Keeping beef warm...............	2.6	154	2.75 "
Parboiling 1 cauliflower..........	8.8	22	1.33 "
Baking the cauliflower...........	8.8	20	1.21 "
Egg sauce for cauliflower	0.6	1	0.04 "
Keeping above warm............	3.1	14	0.29 "
Broiling 4 cutlets.................	5.5	10	0.43 "
Heated pan too soon (wasted)....	5.5	5	0.19 "
Frying potatoes in butter........	5.	25	0.86 "
Total cost of current for cooking luncheon for four......	....	....	8.29 cents.

An excellent luncheon for six, including a steak, fish with tomato sauce, potatoes and rice à la condé was cooked at a cost for current of only 6.91 cents. To heat water for washing dishes and utensils the cost is given as 1.75 cents for 2.5 gallons. A quart of coffee can be made for 0.5 cent. The cost to a family of four for three ordinary meals is calculated to be about 11 to 12.5 cents per day. Electrical energy generally costs more than 3.75 cents, and the above costs would vary accordingly.

458. *What are the advantages of electric heat in the home?*
Electric heat is best adapted to lighting, cooking, ironing and miscellaneous uses where the heat can be localized. It avoids the vitiation of air and the danger of fire incident to matches, kerosene and gas. The devices are easily portable, do not leak or smell, are easily and instantly turned on and off. Electric heat is practicable for warming air in small apartments. Electric fans are helpful auxiliaries to warm-air furnaces by exerting pressure in the intake or suction at inefficient outlets; they improve circulation about radiators. They increase comfort and efficiency by circulating air in hot weather and are invaluable in hospitals.

FIG. 458.—ELECTRIC LAUNDRY.

459. *How may one calculate the watts necessary to raise water a certain number of degrees in temperature?*

A horse-power is 550 ft.-lbs. per second, and also 746 joules per second, or 746 watts; therefore, a watt is .737, and a kilowatt 737, ft.-lbs. per second. A heat unit is equivalent to 778 ft.-lbs.; therefore, a kilowatt will raise a pound of water .94 deg. F. in one second, or 56.4 degs. in one minute; or it will raise 18 lbs. of water from the freezing point to the boiling point in one hour.

460. *How can one make a small electric heater for heating coffee?*

Coil iron, steel or German silver wire on an asbestos pad, insulating the convolutions with asbestos thread. Iron and steel wire have about six times the resistance of copper wire, and German silver wire about twelve times. The lengths per ohm of copper wire at 170 degs. F. are 80, 63, 50 and 40 ft., respectively, for Nos. 20, 21, 22 and 23 wire. From the above data the length of wire for any given current can be found. As an example, for No. 22 iron wire and 5 amp. on a 110-volt circuit, about 220 ft. of wire will be needed.

461. *What length of No. 22 German silver wire, carrying about 5 amp., will be required to heat an electric soldering iron on a 500-volt circuit? Would it be better to connect two or three irons in series?*

The amount of current necessarily depends upon the size of the iron. 100 to 200 watts will heat an iron weighing three-fourths of a pound. To use No. 22 German silver wire and a voltage of 500,

one will need about 1250 ohms, which will be in the neighborhood of 3000 ft., according to the specific resistance of the wire used. No. 22 wire would be too large for such a voltage, as the coil would be bulky

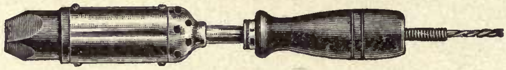


FIG. 461.—ELECTRIC SOLDERING BOLT.

and weigh considerably over 4 lbs. One thousand feet of No. 27 would give the same heat and weigh much less. It is not convenient to connect the irons in series, as all of them would be heated, when, perhaps, but one was to be used.

462. *Will the increase of temperature of a generator be the same whatever the normal temperature is in the room, i. e., will a machine with a given load rise 72 deg. F. above the room when the room is at 60 deg. F. and when it is at 107 deg. F., respectively?*

A machine with a given load will rise to practically the same number of degrees above the atmospheric temperature, no matter what the latter is. If a machine loaded in a room at 60 deg. F. rises to 132 deg. F., it will, with the same load, in a room at 107 deg. F., rise to about 180 deg. F. At the higher initial temperatures the temperature rise will be a little greater owing to the fact that a given number of cubic feet of air blown through the machine will not represent quite so many pounds of air, since, at higher temperatures, it is expanded to a greater volume.

463. *What is the formula for determining the current that will melt copper wire?*

Hospitalier gives the formula $C = 80\, d^{\frac{3}{2}}$, where the diameter, d, is expressed in millimeters. This reduces to $C = .325\, d^{\frac{3}{2}}$ when the diameter is expressed in mils or thousandths of an inch. This formula gives for the melting currents of Nos. 16, 22, 24 and 30 copper wire, 333, 117, 41, 29 and 12 amp., respectively. This formula can not be relied upon for fuses, as it does not take into consideration the cooling effect of the terminals. For copper fuses the melting point should be determined for the style of block used, and for, say, one or two sizes of wire, combinations of which can then be used for larger currents. An approximate rule is that the fusing current is about fifteen times the safe current allowed by the insurance rules.

464. *How can electricity be used to thaw frozen water pipes?*

The best source of current is an alternating system, especially as the temporary wiring for this purpose can be put in the primary cir-

cuits, the transformers being located close to the frozen pipes, and comparatively small wires can therefore be used. A secondary pressure of 50 volts will be sufficient for all ordinary cases. The general arrangement of the circuits is best shown in the accompanying drawing, representing a frozen service from a street main. One lead from the secondary of the transformer is connected to the piping inside the dwelling house or other structure to which the service leads, and the other terminal of the transformer secondary is connected

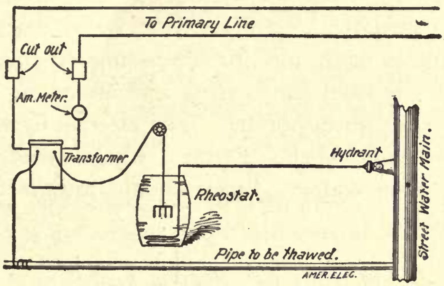


FIG. 464.—THAWING FROZEN PIPE.

through a water rheostat with the street main, either via a convenient hydrant or a service branch to neighboring premises or any other point of access. Care should be taken that the water piping within the house affected is not crossed with other pipes, such as gas pipes, etc., which might give another outlet to the street mains. If the piping of the premises is elaborate and heavily grounded, it would generally prove best to cut it off from the service. The following reports give some idea of the amount of current necessary for different cases: A house connection of 80 ft. of 1-in. pipe was thawed with 180 amp. applied for fourteen minutes. Current was taken from a 100-kw 220-volt direct-current generator, and controlled by a water rheostat made of an ordinary barrel filled with salt water, a coil of bare copper wire in its bottom forming one terminal, and a bundle of seven common arc lamp carbons hung from a piece of line wire forming the upper adjustable terminal. A circuit containing 110 ft. of 1-in. lead pipe and 45 ft. of 6-in. iron pipe was thawed by 155 amp. at 25 volts in seven minutes. Alternating current was used in this case and controlled by a reactive coil in the primary circuit. In another case a ¾-in. lead pipe required 190 amp., the voltage necessary to force this through 85 ft. of the lead pipe, and 22 ft. of 6-in. iron pipe being 30 volts. A 6-in. main 320 ft. long required 350 amp. at 100 volts. A 4-in. cast-iron main was thawed by a current of 160 amp. at 9 volts, maintained for five hours and forty minutes.

465. *How do dentists use electric heat?*

Dentists use heating effects of current for ordinary lighting (see Nos. 467 to 481) and also for special mouth lamps for diagnosing dead teeth and approximal cavities and for finding orifices of canals. They use cauteries for cutting off overhanging gum tissue without hemorrhage, for arresting hemorrhage after extraction and to stimulate healing of old sockets. They use heated tool-points for manipulating gutta-percha and wax, for drying root canals and for assisting pyrozone bleaching. The air syringe with electrical heater is used for desiccating purposes, for destroying septic matter in canals and dentine of pulpless teeth and for obtunding sensitive dentine. The electric annealer is used for heating and annealing gold, and sometimes for softening gutta-percha. The electric oven is without rival for baking porcelain work. Electric water heaters and sterilizers have great hygienic value. Fuses should always be used for protecting apparatus.

466. *How do surgeons use electric heat?*

They use it principally for cautery purposes. Platinum wires are heated by electric current, and applied to parts to be burned off or

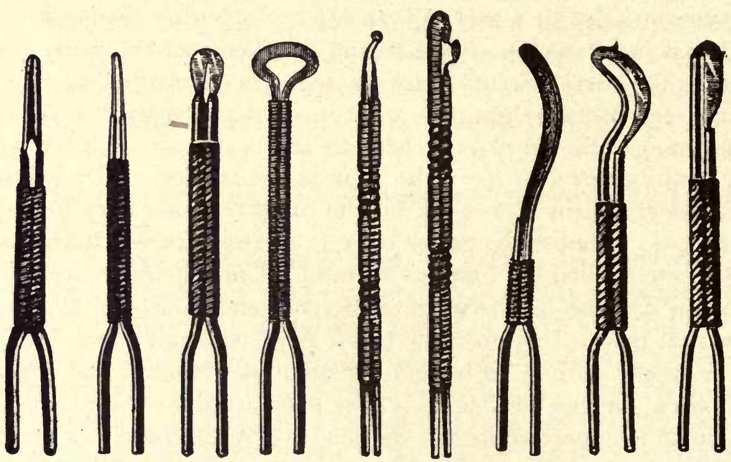


FIG. 466A.—CAUTERY ELECTRODES.

to be seared. By heating the cautery wire white hot and pressing it against fleshy tissue it acts like a knife and makes a smooth cut. By applying a lower temperature the wire will sear the parts and form a sort of scab for stopping hemorrhages, etc. Cauteries are made in various shapes, some being arranged like a snare to be placed

around some undesirable growth, which may then be cut off by tightening the loop while the wire is incandescent. Electric cautery

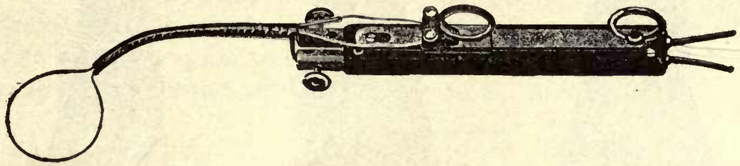


FIG. 466B.—ELECTRIC CAUTERY SNARE.

is applicable in many places where the knife would be used with great difficulty, and the wounds heal rapidly with less danger from after complications. Cauteries require from 2 amp. to 30 amp.

467. *How do physicians use electric heat?*
They use it to some extent for heating poultices and pads to be

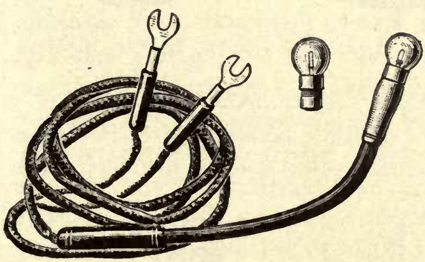


FIG. 467A.—ENDOSCOPIC LAMP.

FIG. 467B.—ELECTRIC POULTICE.

applied to various parts of the body. They also use it for small incandescent lamps, which may be introduced into or near various parts of the body for illuminating purposes.

468. *How is the heating effect of the current used for lighting?*
Current heats to high temperatures a high resistance conductor, as in the incandescent lamp; or it vaporizes the ends of solid conductors, the light coming from their ends as in the ordinary arc lamp, or from the vapor as in the flaming arc; or vaporizes and incandesces mercury.

469. *What are the parts of an incandescent lamp?*
Excepting the Nernst lamp, the light comes from a filament of carbon, platinum, tantalum or tungsten in a vacuum within a glass globe; current enters and leaves through copper and platinum conductors. The glower of the Nernst lamp consists of earthy material similar to that of a Welsbach mantle; it must be heated, usually by

an automatic electric heater, before it becomes a conductor; no vacuum is used.

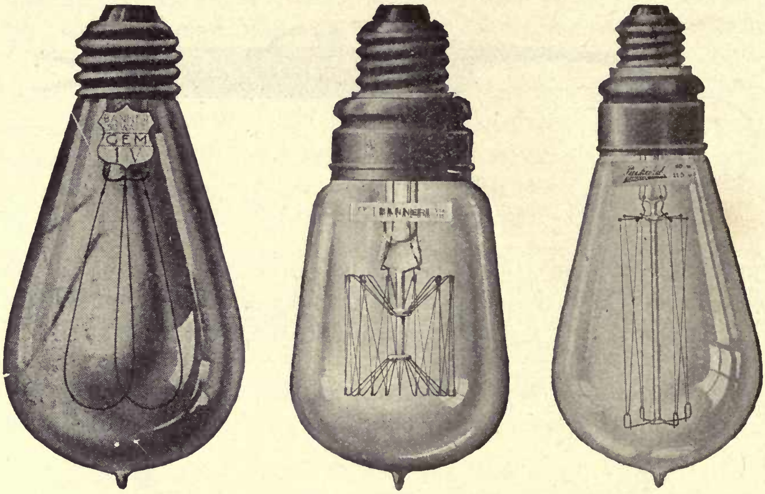


FIG. 469A.—CARBON, TANTALUM AND TUNGSTEN INCANDESCENT LAMPS.

470. *How are incandescent lamps usually operated?*

They are generally connected in multiple between wires having a nearly constant difference of potential. For special purposes, such

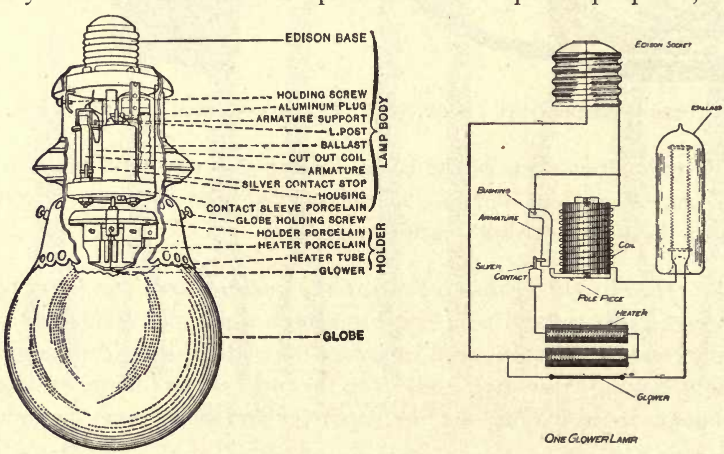


FIG. 469B.—NERNST LAMP, PARTS AND CIRCUITS.

as lighting electric street cars or for lighting streets, a number of lamps are connected in series across lines having 500 to 1000 volts, or even higher. (See Figs. 336 and 337.)

471. *What are the common voltages at which incandescent lamps are operated?*

It was formerly common to use from 50 volts to 55 volts with lamps lighted by alternating currents, but it is now more common to use from 100 volts to 120 volts, or from 220 volts to 250 volts. Lamps on electrically lighted railway cars take 30, 80, 96 or 110 volts. Lamps

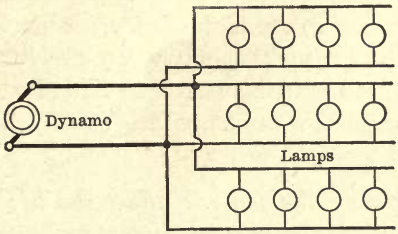


FIG. 470.—INCANDESCENT LIGHT CIRCUIT.

to be operated by current from batteries are made for 3 volts and upward. It is customary to have all the lamps on an installation for the same voltage, and new lamps should be ordered for the voltage regularly maintained. If the lamps are of too high voltage, they will not light up with sufficient brilliancy, the filaments being only dull red or yellow. If the lamps are of too low voltage, they will take too much current and will light up brilliantly, but will quickly burn out. As the lamps get old, they get dim, and sometimes it is practicable to move the old and dim lamps to positions nearer the dynamo, where the voltage is somewhat higher.

472. *What is the relation between voltage and candle-power?*

The candle-power of the light increases much faster than the voltage. For example, a carbon lamp intended to give 16 cp at 105 volts will give 12.5 at 103 volts or 19 at 107 volts.

473. *What is meant by the efficiency of an incandescent lamp?*

The efficiency of an incandescent lamp usually refers to the number of watts absorbed per candle-power. For example, a 4-watt 16-cp lamp would require four times sixteen, or 64 watts. The practice in America is to use carbon filament lamps taking 3.5 or 3.1 watts per candle, " metallized carbon " lamps of 2.5 watts, tantalum lamps of 2 watts and tungsten lamps of 1.25 watts per candle-power. Low voltage lamps for batteries take less energy per candle-power.

474. *What determines the best efficiency to use?*

The cost of power and lamps, and the closeness of regulation of

the voltage are the principal elements. The more costly the power and the cheaper the lamps, the higher should be the efficiency of the lamps. The life of the lamps is shorter when operated at high efficiency, and the life of the lamps is rapidly shortened, if the voltage rises above the normal, so that the voltage should be regulated so as to be as uniform as possible. In plants where the power is unsteady, or where there is much variation in voltage on account of line losses, it is not economical to use high efficiency lamps. On 110-volt circuits 3.1-watt lamps are suitable only where the voltage never varies more than 2 volts; 3.5-watt lamps are suitable for ordinarily well regulated plants, while 4-watt lamps are usually best where regulation is poor. (See also No. 473.)

475. *To what extent does the voltage affect the life of an incandescent lamp?*

This is shown in the following table:

Per Cent of Normal Voltage	Life Factor	Per Cent of Normal Volt'g	Life Factor	Per Cent of Normal Volt'g	Life Factor
100	1.000	103	.562	105	.374
101	.818	104	.452	106	.310
102	.681				

From this it is seen that the life of the lamp is halved by an increase of 3 per cent, and is reduced two-thirds by an increase of 6 per cent in the voltage.

476. *How are the candle-power and efficiency of the lamp affected by variations of voltage?*

This is shown in the following table published by the General Electric Company:

Per Cent of Normal Voltage	Per Cent of Normal Candle-Power	Efficiency in Watts per Candle	Per Cent of Normal Voltage	Per Cent of Normal Candle-Power	Efficiency in Watts per Candle
90	53	4.68	99	94.5	3.22
91	57	4.46	100	100	3.1
92	61	4.26	101	106	2.99
93	65	4.1	102	112	2.9
94	69.5	3.92	103	118	2.8
95	74	3.76	104	124.5	2.7
96	79	3.6	105	131.5	2.62
97	84	3.45	106	138.5	2.54
98	89	3.34			

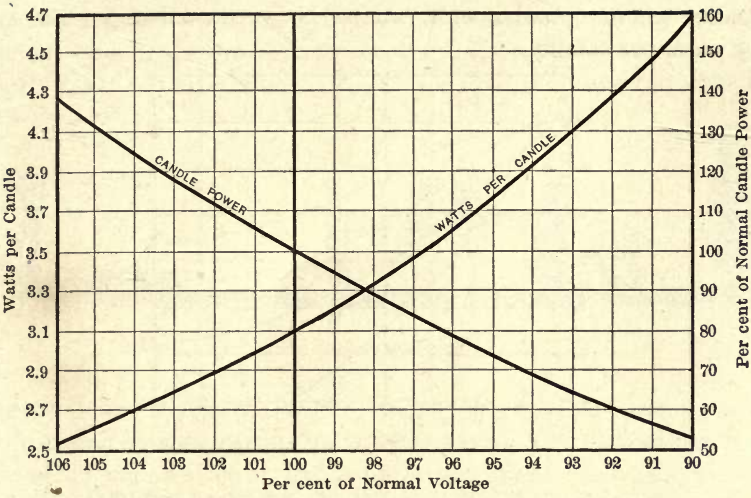


FIG. 476.—VARIATION OF CANDLE POWER AND EFFICIENCY WITH VOLTAGE.

A lamp giving 16 cp with 3.1 watts per candle at 105 volts will give 89 per cent of the light, or 14.5 candles, at 98 per cent of normal voltage, or 103 volts, with 3.34 watts per candle.

477. *What is meant by the smashing point of an incandescent lamp?*

As a lamp gets old its candle-power and efficiency drop off, so that after a certain point it becomes cheaper to throw the lamp away, or to smash it and get a new lamp, than it is to continue burning the old one. The smashing point is generally reached when the candle-power of the lamp has fallen to 80 per cent of its initial value.

478. *How does the candle-power of an incandescent lamp vary with age?*

The candle-power generally increases for a time, and then begins to fall, reaching the initial value at about 100 hours. The rate at which the candle-power falls varies with lamps of different makers, and also with different lamps from the same factory. As the efficiency rises the candle-power falls off more rapidly. The accompanying diagram shows results of careful experiments with an excellent lamp, curve 1 showing the percentage of original candle-power after burning various lengths of time when started at an efficiency of 4 watts per candle, and kept constantly at the same voltage; curve 2 shows a similar lamp started at an efficiency of 3.5 watts per

candle; curves 3 and 4 show similar lamps started at 3 watts and 2.5 watts per candle.

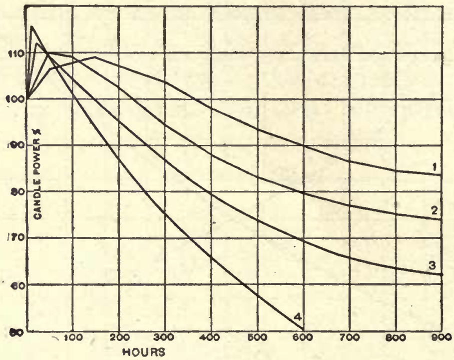


FIG. 478.—LIFE AND EFFICIENCY OF INCANDESCENT LAMPS.

479. *What is meant by a target or shotgun diagram?*

A target diagram shows the watts absorbed and the candle-power of a number of lamps which are tested for uniformity. Such a test should be made for each lot of new lamps bought. The lamps are each placed on a photometer and subjected to the voltage marked on the lamp base, and the watts and candle-power measured at the same time. The readings for each lamp are recorded and also plotted on a

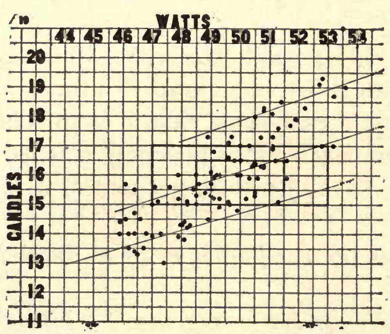


FIG. 479.—TARGET DIAGRAM.

sheet. The record of a test of a poorly sorted lot of lamps is shown in the accompanying target diagram.

480. *What is a photometer?*

The photometer is an apparatus for measuring light. The lamp to be tested is placed at one end of a bar, a standard lamp of known candle-power is placed at the other end, and each is subjected to the voltage specified. A movable screen or "sight box" is then moved along the bar between the two lights until its two sides are equally

lighted by the two lamps. When a balance is found, the strengths of the two lights are directly as the square of the distances from each light to the sight box screen. At the same time the voits and

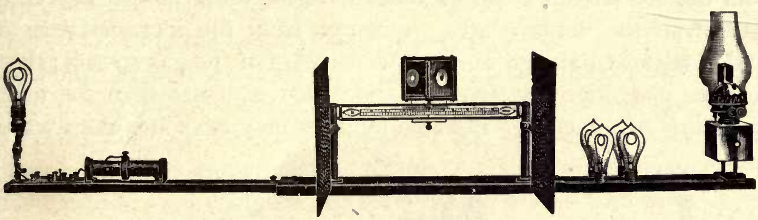


FIG. 480.—PHOTOMETER.

amperes are measured for the lamp under test, and the watts are calculated by multiplying volts by amperes. Instead of an incandescent lamp, an oil or gas lamp is sometimes used as a working standard, as shown in the figure.

481. *What is the temperature of the filament in an incandescent lamp?*

A carbon filament runs at 1700 to 2100 degrees centigrade. If the voltage is too high the lamp takes too much current and the temperature of the filament becomes so high that it becomes soft and droops until it may touch the glass bulb which then cracks and allows air to enter and burn the filament. An abnormally high temperature also causes disintegration of the filament and causes its candle-power to drop off rapidly. Tantalum and tungsten filaments run hotter.

482. *How many incandescent lamps are in use?*

Probably between one and two hundred million. The factories of one company are stated to have a producing capacity of 60,000,000 lamps annually. Within the first two years of its introduction, something like 1,200,000 tantalum lamps were sold in America.

483. *What is the electric arc?*

The electric arc is a phenomenon discovered by Davy about 1800. He sent a strong current through two carbon pencils and then separated them. The current continued to pass, raising the temperature of the ends of the carbons to a high degree, while a vapor of carbon passed between the carbon pencils. By reason of the rising currents of air, the stream of incandescent vapor between the pencils assumed an arched form, and Davy named it the electric arc or arch. Later experiments show that the end of the positive carbon is raised to the temperature of volatilization, that of the arc itself being higher and that of the negative carbon being lower. (See No. 494.)

484. *What is the source of light from an arc?*

Light comes from the ends of the electrodes or pencils, the principal source of light from the open carbon arc lamps; it comes from the arc stream as an incandescent gas, the principal source of light from the flaming arcs; it comes from the incandescence of solid particles entangled in the outer envelop of the gas stream; these particles may give selective radiation, that is, more than the usual proportion of the energy radiated by them may be of luminous wavelength.

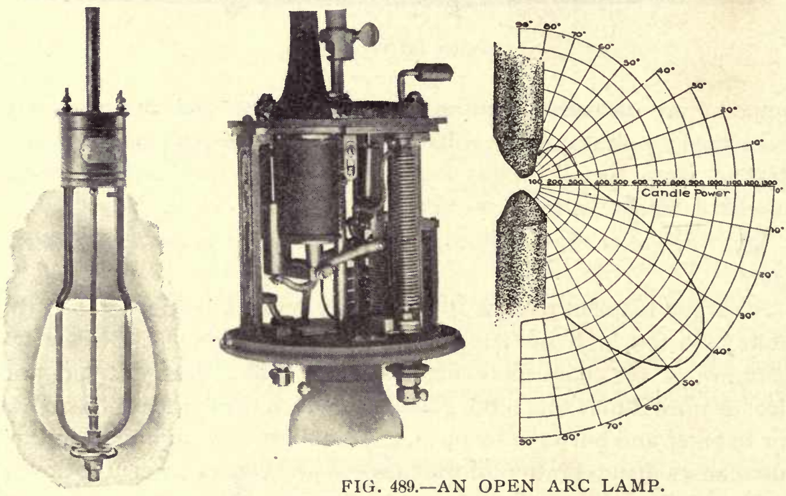


FIG. 489.—AN OPEN ARC LAMP.

485. *What currents and voltages are used by arc lamps?*

Lamps for street lighting are generally operated on series circuits supplied with constant current. The early "low tension" lamps took 20 amperes at 25 to 40 volts; the "high tension" lamps with open arcs took 45 to 50 volts on 9.6 to 10 amperes for "full" or "2000 nominal candle" lights, and 6 or 6.8 amperes for "half" or "1200 candle" lights. The enclosed arcs take 75 to 80 volts on 5 to 6.6 amperes of direct current or 6.6 to 7.5 amperes of alternating current. For interior illumination it is customary to use enclosed arcs adjusted for about 80 volts at the arc and taking 2.5 to 5 amperes of direct current or 4 to 7.5 amperes of alternating current; the enclosed lamps are used singly on 110- to 125-volt circuits, two in series on 220- to 250-volt circuits and five in series on 500-volt circuits, part of the line voltage being taken up by steadying resistances or alternating current choke coils. Flaming carbon arc lamps use 6 to 12 amperes with 40 to 45 volts at the arc with direct current or

38 to 40 with alternating current. Metallic flame or "magnetite" lamps take 4 amperes direct current at 75 to 80 volts at the arc. Focusing lamps, used for lanterns, spot lights and searchlights, take from 10 to 150 amperes.

486. *What is the candle-power of an arc light?*

An open carbon arc lamp with 45 volts at 10 amperes has 1200 to 2000 cp in a direction about 40 degrees below horizontal, 300 to 400 cp horizontally and an average of about 600 cp over the lower hemisphere. The 6.8 ampere open arc gives about 60 per cent of the above values. An enclosed arc lamp taking about 5 amperes direct current from a 110-volt circuit gives about 320 cp 30 to 40 degrees

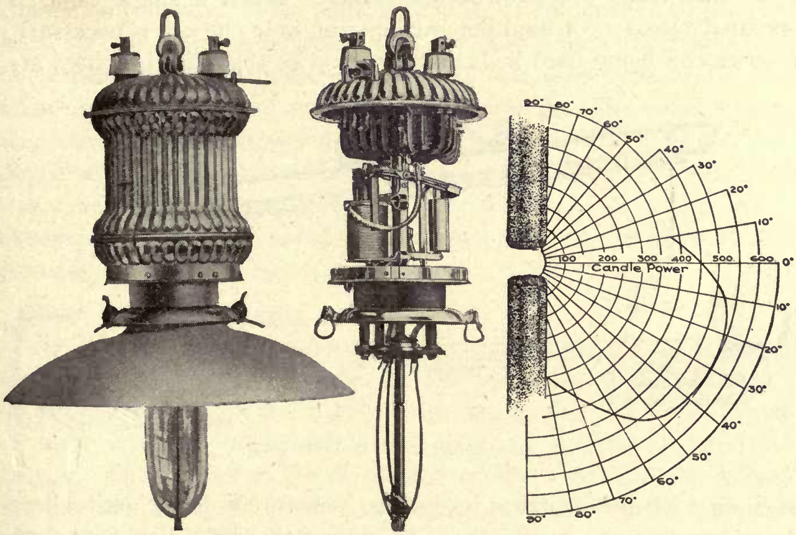


FIG. 490.—AN ENCLOSED ARC LAMP.

below the horizontal, about 230 horizontally and an average of about 240 over the lower hemisphere. Alternating current arcs give about 25 per cent less light than direct-current arcs taking equal energy. A flaming arc taking 10 amperes with 46 volts at the arc gives about 1500 horizontal cp and an average of about 3000 over the lower hemisphere. A magnetite arc taking 4 amperes and 80 volts gives about 550 horizontal cp and an average of about 370 over the lower hemisphere. A direct-current mercury-vapor tube taking 385 watts gives a maximum of about 730 cp directly underneath and an average of 400 to 750 over the lower hemisphere.

487. *How long do the electrodes last in arc lamps?*

In a 9.6 ampere direct-current open arc, a positive carbon 12

inches long and 0.5 inch in diameter lasts from 7 to 12 hours, a negative of equal size lasting from one to three times as long; for all-night operation it is necessary to have a double lamp. The carbons in enclosed lamps last from 80 to 200 hours. Flaming arcs need retrimming or re-carboning after 10 to 20 hours. The metallic flaming or magnetite lamps require trimming about every 150 hours.

488. *How are the arc electrodes kept the right distance apart?*

Each lamp has a mechanism, usually driven by gravity and controlled by electromagnets. A coil in series with the arc and carrying the whole current is generally used to move the electrodes apart, and a coil of comparatively high resistance shunted around the arc commonly feeds the electrodes together. When a single lamp is operated across a constant potential circuit, only one coil is necessary, a series coil being used in lamps arranged so that the electrodes are

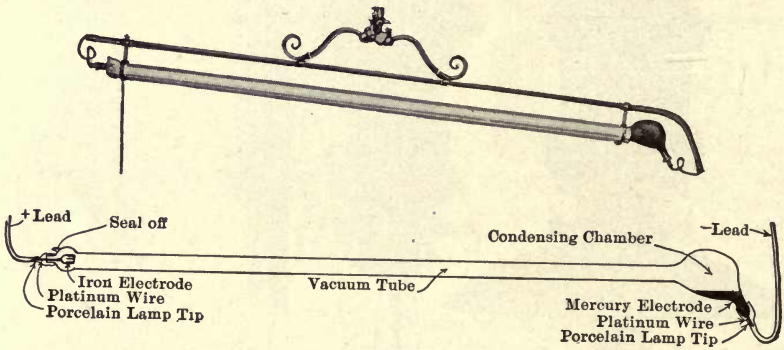


FIG. 493.—MERCURY VAPOR LAMP.

in contact when no current is passing, a shunt coil being used where the electrodes are apart when no current passes. For lamps on series circuits, a cut-out coil is necessary to prevent excessive voltage at one lamp or to prevent opening the entire circuit in case a lamp fails to feed; for constant current circuits, the cut-out coil short-circuits the lamp; when several lamps are operated in series across constant potential mains, the lamp cut-out substitutes an equivalent dead resistance when the lamp fails to feed, or else the entire "string" of lights is extinguished. When the exact position of the arc is unimportant, only one electrode is moved, this being the positive except in case of magnetite or "metallic flame" lamps. The general basis of arc lamp regulation is that with a given current, the effective resistance of the arc and the difference of potential between its terminals vary with the length of the arc; consequently, the longer the arc the more current will pass through the shunt coil

and the stronger it will pull its armature and the attached mechanism. (See Nos. 726 to 736.)

489. *What is an open arc?*

In the open arcs, the electrodes are of nearly pure carbon, a glass globe surrounding the arc to protect it from wind. The positive electrode is above, the end assuming a cup shape called the crater and being the principal source of light. The arc stream gives little light, simply adding a violet tinge when long.

490. *What is an enclosed arc?*

With the enclosed arc lamps a small glass globe surrounds the arc and fits the carbon pencils so closely that the air inside the globe can change only slowly. This reduces the rate of combustion of the carbons, so that they last longer. This not only reduces the frequency of retrimming (recarboning) the lamp, but also reduces the demands upon the feeding mechanism of the lamp. The arc is longer, the crater less distinct and the arc less efficient. The light is better distributed, being stronger horizontally and without intense contrasts below. The longer life of the carbons, even though more expensive in first cost, saves the operating company from $7 to $10 annually. (See also Nos. 485 to 487.)

491. *What is a flaming arc?*

The flaming arc lamp uses electrodes consisting of a carbon shell with a core of powdered carbon, mineral salts and a suitable binder; the minerals make the arc highly luminous, so that the total amount of light is about treble that from ordinary carbons using equal energy. On account of the fumes and residue from the mineralized carbons, the arc must be well ventilated, and is best suited for exterior lighting. The electrodes are generally inclined, making a narrow "V" and throwing most of the light downward, the arc being deflected by an electromagnet. (See Nos. 485 to 487 and 502.)

492. *What is a magnetite or metallic flame lamp?*

In these lamps, the negative electrode furnishes the material for the arc vapor, and consists of a thin steel tube packed with oxides of metals such as iron (magnetite), titanium and chromium. In vaporizing, these add great luminosity to the arc; they leave a considerable amount of fluffy soot which is carried away by special ventilation. One electrode is directly above the other, one company having the positive above, another the negative.

493. *What is the mercury vapor lamp?*

The Cooper-Hewitt lamp consists essentially of a glass tube hav-

ing at each end a bulb containing mercury and a platinum leading-in wire, the air being exhausted. A tube about 4 feet long and 1 inch in diameter takes about 3 amperes direct current at about 110 volts, giving a strong greenish light. The lamp is commonly started by tipping the tube until a thin stream of liquid mercury makes connection between the two electrodes; when the tube is tilted back, an arc is started which fills the tube with ionized mercury vapor which forms a luminous path between the lower cathode and the upper anode (see Nos. 607 and 644). Special devices are made for making the lamp self-starting, even without tipping. They are sometimes used with alternating currents.

494. *What are the temperatures in the arc?*

There is some variation in the results of different investigations, but the temperature of the crater at the end of the positive carbon is between 3500 deg. and 3900 deg. C. The temperature of the end of the negative carbon is about 2500 deg., while the temperature of the arc itself is reported as 3900 deg. to 4800 deg. The arc has about the highest temperature obtainable.

495. *Is any use other than lighting made of the high temperature of the arc?*

Various processes for welding metals and for the reduction of metals or other metallurgical work have been developed both from the heat of the arc and also from the heat from the ordinary operation of the current. These are sometimes classified as incandescent and arc processes.

496. *What different processes are there for electric welding?*

There are three classes of processes: that of Thomson, who sends a heavy current through the two pieces whose ends are placed in close contact and are pressed together when the current has heated their ends to a welding temperature; a second class is that developed by Bernardos and others, who use the arc to heat the metals to the desired temperature; a third method is developed from the "water pail forge" of Lagrange and Hoho.

497. *Describe the Thomson welding process.*

The Thomson welding process consists in clamping together the pieces to be welded, and then sending a heavy current through the clamp and the joint. The resistance at the joint is higher than elsewhere, and the great heat developed there (see Nos. 371 and 415) quickly raises the joint to a welding temperature. The parts are then forced together mechanically, completing the weld. Most of the heat is developed exactly where required, part being carried away

by the clamps and some heat being developed in other parts of the circuit. The process is economical and easily competes with fire welding. By adjusting the current strength, pieces of any size may be welded without burning. Some welds easily made electrically are difficult or impracticable by other processes. Alternating current is best adapted for welding, since large currents at low voltage are easily generated close to the work by the use of transformers (see Nos. 1404 and 1405). When direct current only is available, a converter (see Nos. 498 and 1510 to 1512) supplies alternating current. The welding of copper requires about 60,000 amperes per square inch of metal. An interesting process is the welding of rails for electric roads.

498. *How are rails electrically welded?*

One car carries a rotary transformer which changes a current of about 275 amp. at about 500 volts from the trolley line into an alternating current of 300 volts. The alternating current passes to the welding transformer, which is hung on a crane behind the car. The

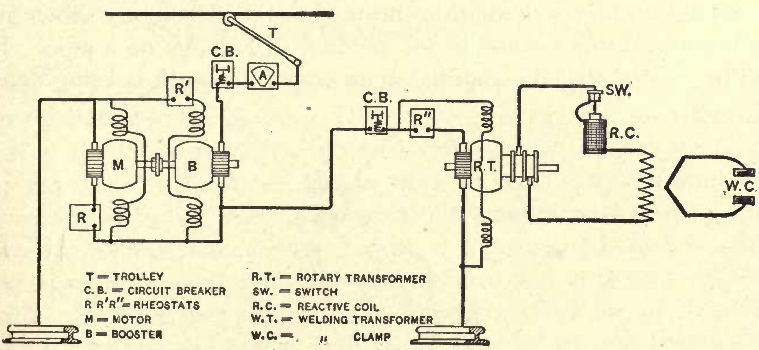


FIG. 498.—ELECTRIC RAIL WELDING.

rails to be welded are butted against each other and two chucks are welded from either side to the ends of the two rails. A hydraulic jack forces the chucks against the cleaned ends of the rails and so completes the weld after the current has supplied the necessary heat. About four welds can be prepared and finished in an hour.

499. *Is the heating effect of the current used for metal working other than welding?*

Thomson has used heavy currents for heating and annealing spots in steel armor plates where it is desired to drill holes or to do other

work. The heating effect of the current, either passing through the material itself or through an oven or furnace (see No. 503), is used for tempering springs, annealing, heating for forging, etc.

500. *Describe the water pail forge.*

Lagrange and Hoho found that if an electric circuit was closed by dipping the negative terminal into a conducting liquid, the cathode or negative terminal became very hot and melted if the voltage was above 125. This has been developed by Burton and others into what is known as "hydro-electric heating." The best solution is ten parts of carbonate of soda and one part of borax dissolved in water until the specific gravity is 1.15 at 70 deg. F. Metals can be heated for welding, or the heat may be graduated for such purposes as heating soldering irons.

501. *How is the arc used for welding?*

The arc welding system is suitable for surface work and has been applied by Bernardos and others for such work as filling blow-holes in castings and for welding thin sheets of metal. The figure shows an application of this method to the welding of a flange on a pipe. It will be noticed that the material upon which the work is being done

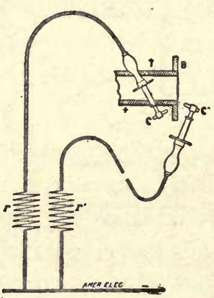


FIG. 501.—BERNARDOS' ARC WELDING PROCESS.

is connected to the positive terminal of the circuit, while the carbon points, which are held in the workman's hands, are connected through the resistances, rr', to the negative side of the circuit. This operation is said to work with great rapidity and satisfaction, but a practical point of much importance in connection with it is to heat the metal to be operated upon to a dull red heat in an ordinary fire before exposing it to the arc temperature. The process is used considerably on the Continent for the repairing of boilers, cracks and fissures in steel plates being easily mended in this manner and filled

up with melted metal. Zerner and others have modified this method by blowing an arc against the surfaces to be heated, so that the materials acted upon do not become part of the electrical circuit. This is sometimes called an electric blowpipe.

502. *Describe the electric blowpipe.*

Zerner's blowpipe is illustrated in the figure. An arc at a potential difference of about 85 volts and with a current of 20 amp. is established between the carbons *C* and *C′*. The two coils, *S*, are solenoids, producing a magnetic field in a direction at right angles to that of the arc, causing the latter to be projected to one side, as shown

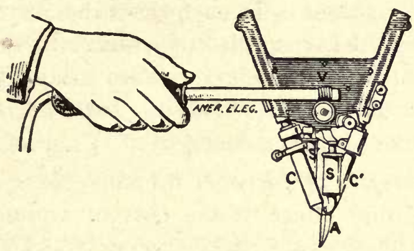


FIG. 502.—ZERNER ELECTRIC BLOWPIPE.

at *A*. The regulation of the carbons is effected by the screw *V*, as clearly shown in the figure. This simple apparatus is used a great deal in England, especially in the manufacture of bicycles for brazing the tubes of the frame, and in work on thick plates of steel, as, for example, boiler iron. The great advantages possessed by this form of instrument are at once evident, as it is easily handled, is light, and gives an exceedingly high temperature and at a very definite point. Both the Bernardos and the Zerner methods are successfully used for cutting up metals, such as the removal of iron beams and large riveted tanks from the interior of buildings.

503. *What is an electric furnace?*

An electric furnace is an arrangement for obtaining a high temperature in an inclosed space by means of the heat from an electric current. Electric ovens are made for comparatively low temperatures, like electric heaters (see No. 455) having a cavity inside and being lagged to hold in the heat. For higher temperatures, furnaces are made on both the arc and the incandescent principles (see Nos. 468, 481, 494). In the incandescent or resistance type of furnace, the material is heated by current passing either through it or through a conducting core or tube. In the induction furnace, the material heated constitutes an entire circuit by itself, being the secondary of a transformer (see Nos. 1404, 1405). In the arc type

of furnace, the material is either passed directly through the arc stream or it is acted upon by heat conducted from the arc. Both arc and resistance effects are used in some furnaces, and some add chemical action of the current.

504. *How is the electric furnace used?*

The high degree of heat obtained is used in effecting chemical combinations of various materials. In some cases the elements of the different ingredients simply combine to form new combinations. At the high temperatures attained in some electric furnaces, the ingredients dissociate, that is, separate so that the elements are free to form new combinations. In such cases the current is simply the source of heat and does not directly enter into the reactions. In other cases the current not only furnishes a high temperature, but also takes direct part in the reactions, both the heating and the chemical effects of the current being used.

505. *Give examples of furnaces in which these effects are used.*

The simple heating effect of the current without any chemical action is used in furnaces for making artificial graphite from carbon and artificial corundum ("alundum") from bauxite (oxide of aluminum), etc. The heating effect as a means of inducing chemical action is used in furnaces for making calcium carbide, carborundum (carbide of silicon), carbon bisulphide, phosphorus, arsenic, cyanides, siloxicon, ferro-alloys, etc.; for fixing atmospheric nitrogen, smelting ores and refining metals. The combined heating and chemical effects of the current are used in the production of aluminum, caustic soda, sodium, etc.

	Name.	Formula	Discoverer	Remarks.
Decomposed by water	Aluminum	Al_4C_3	Moissan, 1894	Water evolves methane
	Barium	BaC_2	" 1894	" " acetylene
	Calcium	CaC_2	Wohler, 1862	" " "
	Cerium	Ce_2C	Moissan, 1896	" " " ethylene and methane
	Glucinum	Gl_4C_3	Lebeau, 1895	" " methane
	Lanthanum	LaC_2	Moissan, 1896	" " acetylene, ethylene and methane
	Lithium	Li_2C_2	" 1896	" " acetylene
	Manganese	Mn_3C	Troost and Hautefeiulle	" " methane and hydrogen
	Potassium	K_2C_2	Davy, 1808	" " acetylene
	Sodium	Na_2C_2	Berthelot, 1866	" " "
	Strontium	SrC_2	Moissan, 1894	" " "
	Thorium	ThC_2	Moissan, Etard, 1896	" " acetylene, hydrogen and hydrocarbons
	Uranium	Ur_2C_3	Moissan, 1896	Water evolves acetylene, methane, hydrogen and solid and liquid hydrocarbons
	Ytrium	YC_2	Petterson, 1895	Water evolves hydrogen
	Zirconium	Z_2C	Moissan, 1896	" " methane, acetylene and ethylene
Not decomposed by water	Boron	B_6C	" 1894	Harder than corundum
	Chromium	Cr_3C_2	" 1894	" " topaz
	Molybdenum	Mo_2C	" 1893	
	Silicon	SiC	Acheson, Moissan, 1893	" " corundum
	Titanium	TiC	Moissan, 1895	Takes fire at red heat
	Tungsten	W_2C	" 1893	Harder than corundum
	Vanadium	VaC	" 1893	" " quartz

506. *Are there other carbides than those of calcium and silicon that are or can be made in the electric furnace?*

Quite a number have been discovered, as shown in the table:

507. *How is calcium carbide made?*

Calcium carbide is formed by the union of carbon and calcium at a high temperature. The calcium is obtained from common line, which is calcium oxide, and is represented chemically by the abbreviation CaO. When this is ground fine and well mixed with powdered coke (carbon), the latter unites with both the elements in the lime, two atoms of carbon uniting with one atom of calcium to form calcium carbide (CaC_2), the other atoms of carbon uniting with equal numbers of atoms of oxygen to form a gas known as carbon monoxide (CO). The carbon monoxide escapes from the furnace and unites with oxygen of the air, burning with a blue flame and forming carbon dioxide (CO_2), which is more familiarly known as carbonic acid gas. The reaction is expressed by the chemical equation,

$$CaO \text{ (calcium oxide)} + 3C \text{ (carbon)} = CaC_2 \text{ (calcium carbide)} + CO \text{ (carbon monoxide)},$$

which is read: one molecule of calcium monoxide unites with three molecules of carbon to form one molecule of calcium carbide and one molecule of carbon monoxide. The calcium carbide is a bluish gray structureless mass easily crumbled to powder. It unites greedily with water forming acetylene gas (C_2H_2) and slacked lime ($Ca(HO)_2$), the reaction being expressed by the formula: CaC_2 (calcium carbide) + $2H_2O$ (water) = C_2H_2 (acetylene) + $Ca(HO)_2$ (calcium hydroxide). Acetylene is a colorless and highly explosive gas with very disagreeable smell, burning with a brilliant light, but apt to give a smoky flame. It can be liquefied at a pressure of about 725 lbs. per square inch at the temperature of freezing water. It is coming into extensive use as an illuminant.

508. *How is carborundum made?*

Carborundum is made in an electric furnace from a mixture of sand, coke, sawdust and salt. The real action is between the sand, which is oxide of silicon (SiO_2) often called silica, and the carbon in the coke and sawdust. The sawdust makes the mixture porous to facilitate the escape of gases, and the salt seems to act as a sort of flux. At the high temperature the silica is dissociated, its silicon uniting with carbon to form carbide of silicon (SiC), and its oxygen uniting with other carbon to form carbon monoxide (CO), which

then unites with more oxygen from the air and burns into carbonic acid gas (CO_2). The formulæ are:

SIO_2 (silica) + $3C$ (carbon) = SiC (carbide of silicon) + $2CO$ (carbon monoxide);

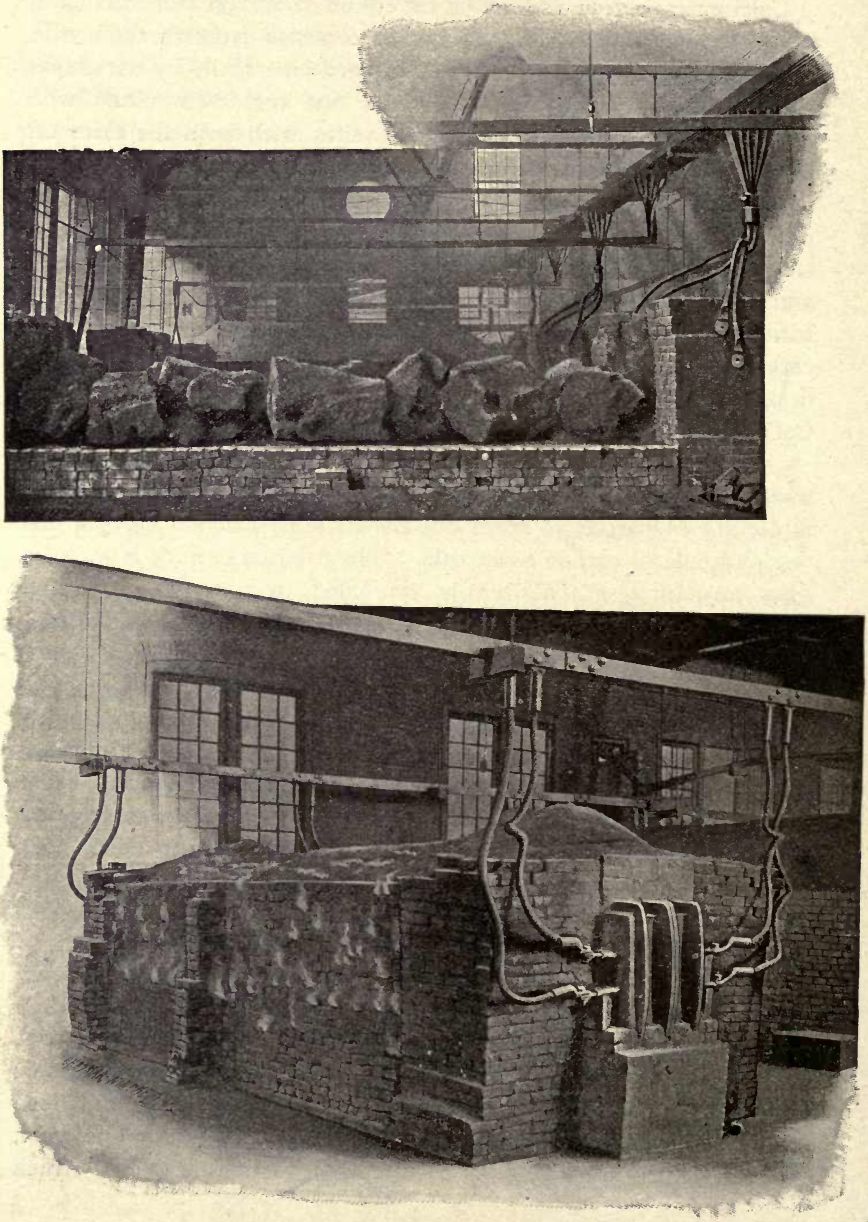


FIG. 509.—CARBORUNDUM FURNACE.

2CO (carbon monoxide) + O_2 (oxygen) = $2CO_2$ (carbonic acid gas). The carbide of silicon, or carborundum, forms in small flat, thin crystals of beautiful colors. These are crushed and made into various shapes for abrasives, doing much of the work for which emery was formerly used.

509. *In what sort of an electric furnace is carborundum made?*

As used by the Carborundum Company at Niagara Falls, the furnace walls are of brick, being about 16 ft. long, 5 ft. wide and 5 ft. high, the ends being of brick about 2 ft. thick. In the center of each end are the terminals, each consisting of six carbon rods 30 ins. long and 3 ins. in diameter, attached to an iron plate. A central core between the two sets of carbon rods is made of coke surrounded by the mixture of sand, coke, sawdust and salt, making a cylinder about 21 ins. in diameter and 14 ft. long. The side walls, which are taken down at each charge, are then built up and the remaining space is filled with the mixture. Current of something more than 1000 amp. at 100 volts to 250 volts is then sent through the furnace for about twenty-four hours. This furnace works on the incandescent principle, there being no true arc present.

510. *In what sort of a furnace is calcium carbide made?*

Several different furnaces are employed, nearly all of them being of the arc type. One of the simplest is that used by Borchers, an eminent German chemist, consisting of two large carbon rods which pass through limestone or similar non-conductor. These rods are separated a short distance and are connected by a small carbon rod which is surrounded by the material (carbon and lime for calcium carbide) to be acted upon. When a heavy current passes, the small carbon rod is heated to incandescence and is burned; an arc then follows and the high temperature fuses the carbon and lime, which

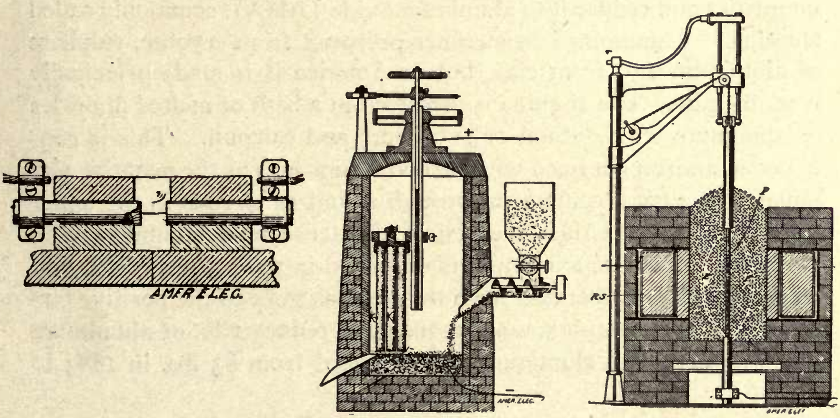


FIG. 510.—ELECTRIC ARC FURNACES.

then unite as noted in No. 507. The furnaces mostly used in the United States have two carbons arranged one above the other; the upper one is movable vertically and also sometimes horizontally. After the arc is struck, the upper carbon is gradually raised as the material below it is changed. In some of the furnaces the arc is maintained at 65 volts to 70 volts, and the current is from 400 amp. to 1000 amp. To produce one ton of carbide requires about 200 hp-hours. In some of the furnaces one of the carbons rotates slowly, so as to keep acting on new material.

511. *How is atmospheric nitrogen fixed by electrical methods?*
At high temperatures nitrogen combines chemically with oxygen in equal parts to form nitric oxide (NO). In the Bradley-Lovejoy process, nitrification was accomplished by passing air through a chamber in which an arc was broken about 7000 times a second. In the Birkeland process, now in commercial use, air is passed through an alternating current arc of large section. The resulting nitric oxide is rapidly removed and is combined with water, caustic soda, etc., to form various nitrates and nitrites used for fertilizers, explosives, etc.

512. *What kind of current is used in electric furnaces?*
Either direct or alternating current may be used in incandescent and in some of the arc furnaces. Only the direct current can be used in furnaces dependent partly or wholly upon the chemical effect of the current, as in the production of aluminum.

513. *How is aluminum produced?*
Aluminum is made from bauxite, a compound of aluminum, oxygen and water. The ore, which is obtained principally from Georgia and Alabama, is treated by chemical processes to remove impurities and reduce it to aluminum oxide (Al_2O_3), commonly called alumina. Aluminum is sometimes prepared from cryolite, sulphate of aluminum and from clay, but in America it is made principally from bauxite. The alumina is dissolved in a bath of melted fluorides of aluminum with sodium or potassium and calcium. This is contained in an iron pot lined with carbon, which acts as the negative terminal, the current coming in through cylinders or rods in the upper part of the pot. Under the action of intense heat, combined with electrolysis, metallic aluminum is deposited in the bottom of the pot, while the oxygen liberated from the alumina goes to the positive terminal. About 5 hp-hours are required to reduce 1 lb. of aluminum. The production of aluminum has increased from 83 lbs. in 1883 to

550,000 lbs. in 1894, and 8,000,000 lbs. in 1898, more than half of the production being in the United States. The price of aluminum has fallen from $250.00 per pound in 1855 to $0.25 in 1900.

514. *What is the difference between aluminum and aluminium?* The two are simply different forms of the same word, the former being somewhat easier and shorter to pronounce. On account of the difficulty in distinguishing between aluminum and alumina as pronounced, the men around the reduction works use the longer word aluminium (pronounced a-lu-min-i-um), rather than aluminum (pronounced (a-lu-mi-num).

515. *Where can further accounts of electric furnaces be found?* "Electric Furnaces and their Industrial Applications," by J. Wright; "Electric Smelting and Refining," by W. Borchers and W. G. McMillan; "The Electric Furnace," by Moissan; Transactions of the American Electrochemical Society; Electrochemical and Metallurgical Industry. Sections on "Electrochemistry" in "Standard Handbook for Electrical Engineers" and in Foster's "Electrical Engineer's Pocket Book."

CHAPTER V.

BATTERIES AND ELECTROCHEMICAL ACTION.

600. *What is the relation between chemistry and electricity?*

When a current passes through any liquid conductor, the liquid is decomposed or otherwise chemically changed, unless it is a chemical element such as mercury or a melted metal. On the other hand, when two conducting substances are immersed in a liquid which dissolves one more than the other, an electromotive force is found to exist between the two. The latter is the basis of all batteries for generating electricity. The former is the basis of the storage battery, and of many applications of electricity to medicine, to chemical manufacture, to electrical measurement, to electro-plating, and many other processes. (See Nos. 815 to 821 under Instruments.) There is a definite relation between the amount of electrical energy absorbed and the chemical action produced in each case. Chemical action may also be caused indirectly by electricity, as in the electric furnace, where the heating effect of the current causes very high temperatures which loosen the bonds and allow compounds to break up so that their elements may unite in new combinations. (See Nos. 503 to 513). This is the basis of electro-metallurgical processes, such as the manufacture of calcium carbide and carborundum. Chemical action, like heat, may thus cause, or be caused by electricity.

601. *What is a chemical cell or battery for generating electricity?*

It consists of two pieces of conducting substances in a liquid that acts chemically upon one more than upon the other. In primary cells one of the substances is generally a rod or plate of zinc, a metal that is cheap and also easily acted upon by solutions of common salts. The other substance is generally carbon, copper or iron. The solution is generally sal ammoniac, or copper sulphate, or caustic potash. Sometimes acids are used. The conductor that is least eaten by the liquid becomes positively charged and the other negatively charged. In secondary cells the conductors generally consist of lead and its compounds, and the liquid is dilute sulphuric acid.

602. *What is the difference between a cell and a battery?*

The word "battery" refers strictly to a number of cells coupled together. It is quite common, although inaccurate, to use the word when referring to a single cell. The word "cell" often refers to the containing vessel.

603. *What is a voltaic or galvanic battery?*

These are simply other names for chemical batteries. Volta and Galvani are the two men who divide honors for discovering the principle and inventing the battery.

604. *For what purposes are batteries used?*

Where small currents are used, as for electric door bells, telegraph lines, telephone transmitters, medical purposes and for very small motors, primary batteries are usually the most convenient source of current. Where larger quantities of electricity are required, as for operating electric automobiles, telephone exchanges and for use in connection with central stations for electric light and power, the storage battery has a useful field.

605. *What is the difference between a primary and a secondary battery?*

When a primary battery is exhausted, it is necessary, as a rule, to throw away the electrolyte and supply a new one, also frequently renewing the electrodes. Storage batteries are recharged by sending a current through them in the opposite direction from that which the battery delivers, the same electrolyte and electrodes being used over and over again. In the secondary, or storage, battery there is no storing of electricity as such. The charging current reverses certain chemical actions (see Nos. 635 to 638), and the energy that is stored is chemical rather than electrical. The only case where electricity is stored as such is in the condenser or Leyden jar. (See Nos. 111 to 123.)

606. *What is an electrolyte?*

Liquids may be classified into three divisions: those that do not conduct electricity at all, such as oils; those that conduct electricity without any chemical effects, such as mercury and other metals in liquid form that act like solid metals; and those that are decomposed by the passage of current. Liquids of the third class are called electrolytes.

607. *What is an electrode?*

Electrode is a name for the solid conductors which lead the current to and from the electrolyte. The anode, sometimes thought

of as "in-ode," is the plate at which the current enters the liquid, being the positive terminal. The cathode is the plate at which the current leaves, being the negative terminal.

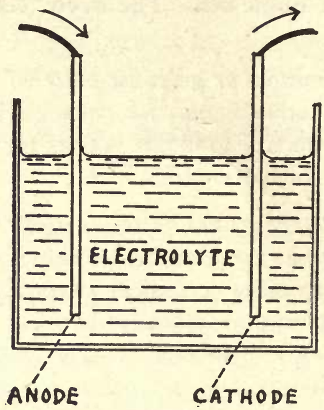


FIG. 607.—ELECTROLYTIC CELL.

608. *What is meant by the electro-chemical series?*

The difference of potential between the electrodes varies with different substances. For example, zinc and copper give several times as much E.M.F. as zinc and iron, while zinc and carbon give still more. It is found also that if copper and carbon be placed in dilute acid, they form a battery; current will flow from the carbon through the wire to the copper, and the carbon is said to be electro-positive to the copper. On the other hand, if copper and zinc are used, the copper is the more positive and current flows through the wire from copper to zinc. The various elements may be arranged in such an order that each is electro-positive to those following and electro-negative to those preceding. The common order is as follows: Oxygen, sulphur, selenium, nitrogen, fluorine, chlorine, bromine, iodine, phosphorus, arsenic, chromium, vanadium, molybdenum, tungsten, boron, carbon, antimony, tellurium, titanium, silicon, hydrogen, gold, platinum, palladium, mercury, silver, copper, bismuth, tin, lead, aluminum, cadmium, cobalt, nickel, iron, zinc, manganese, uranium, magnesium, cacium, strontium, barium, lithium, sodium, potassium. The order of these elements varies to some extent with the electrolyte.

609. *How can one tell which is the positive and which the negative terminal of a battery?*

In most cells the electrodes are of different metals, and only one is dissolved into the solution. The metal which is subject to the more

vigorous chemical action may be considered as the fuel that supplies the energy, and it is called the positive plate. But it is always found that the metal which is the more active chemically is electro-negative to the other. So it comes about that the positive plate constitutes the negative terminal of the cell, and the negative plate is the positive terminal of the cell. Thus, zinc is generally used for the positive plate in cells, and the zinc is generally the negative terminal of the cell. The rule is easily remembered that the substance not destroyed is the positive terminal of the cell.

610. *How many kinds of batteries are there?*

Batteries are classified as primary and secondary, as noted already. Primary batteries are further divided into "open circuit" and "closed circuit" batteries. They may also be divided into three classes, accordingly as the depolarizer is mechanical, chemical or electro-chemical.

611. *What is meant by an open circuit battery?*

An open circuit battery is one that is suited for only intermittent work, such as operating door bells and similar purposes. Such cells polarize quickly when in operation, so that their resistance rapidly increases and diminishes the current after a few minutes. Such cells recover after a time as the polarization gradually disappears.

612. *What is meant by the polarization of a battery?*

When the cell is generating current, the metal dissolved from the positive plate combines with the electrolyte, and forms with it a new compound. Usually the dissolved metal displaces hydrogen gas, which appears in the form of bubbles on the surface of the negative plate. These bubbles diminish the amount of surface of plate in contact with the liquid, and so increase the resistance of the cell, and thus reduce the current. The hydrogen bubbles are strongly electro-positive, and so set up an opposing E.M.F. which further reduces the current.

613. *How is the polarization removed?*

In some cells the gas bubbles rise to the surface and escape to the air, the surface of the negative plate being made rough, so as to offer many fine points where the gas may collect and escape. In other cases a "depolarizer" is provided to unite chemically with the gas, and form a substance that will dissolve in the liquid. For this purpose black oxide of manganese, oxide of copper, red lead, peroxide of lead, sulphur, bromine, chlorine, nitric acid and solutions of chromic acid, of bichromate of soda, of bichromate of potash, of nitrate of

potash and of ferric chloride are used. Some of these attack zinc even when the circuit is not closed, and must be used with care. The solid depolarizers generally work only slowly, and are used in cells for intermittent work on circuits that are generally open. Liquid depolarizers generally work rapidly, and the cell may be used continuously with but little diminution of the E.M.F.

614. *What are examples of open circuit batteries?*

The cells using carbon and zinc for electrodes usually polarize in a short time. The electrolyte is usually a solution of sal ammoniac (ammonium chloride) in water, although other salts are sometimes used. The larger the amount of surface on the carbon electrode, the longer the cell will deliver current without troublesome polarization. The larger the surface of carbon and of zinc, and the closer they are together, the less the internal resistance of the cell and the more current it will deliver. Excellent forms of sal ammoniac cells are

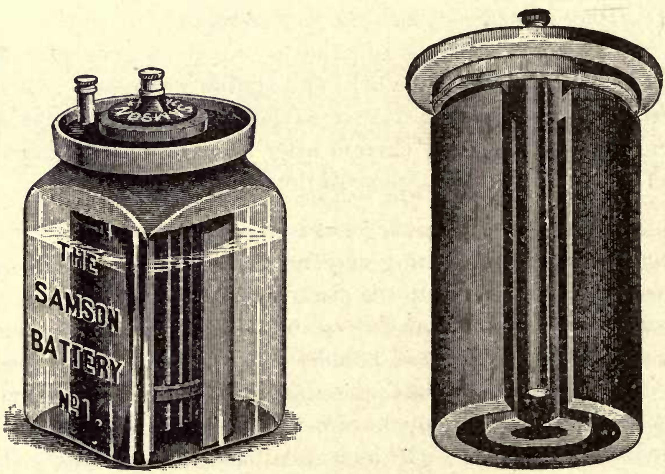


FIG. 614.—SAL AMMONIAC CELLS.

shown in the figures. Some have a depolarizing substance in connection with the carbon, while others depend on the large surface and the slow removal of the polarizing gases.

615. *Explain the action of the sal ammoniac cell?*

This cell consists of carbon and zinc electrodes, immersed in a solution of sal ammoniac (NH_4Cl), technically known as ammonium chloride. The solution has no effect on either electrode when the circuit is open. But when the circuit is closed, the zinc is dissolved, and breaks up the sal ammoniac to form zinc chloride ($ZnCl_2$),

ammonia gas (NH_3), and hydrogen gas (H_2). The ammonia immediately dissolves in the water of the solution and forms ammonia water (NH_4OH), while the hydrogen collects on the carbon electrode. In many cells, such as the Law, Diamond and Laclede cells, the hydrogen simply collects on the carbon during the action of the cell, and then gradually rises to the surface, and escapes to the air while the cell is resting. The larger the surface of the carbon, the longer the cell will work without rest. Other forms of sal ammoniac cell have a chemical depolarizer, and are known by the general name Leclanche cell. Sal ammoniac cells give from 1.3 to 1.7 volts when new.

616. *Explain the action of the Leclanche cell?*

In the Leclanche cell the carbon is placed in contact with some solid substance which will unite chemically with the hydrogen, and so remove the polarization. In the original Leclanche cell the carbon was placed in a porous cup, which was then filled with manganese dioxide (MnO_2), which readily gave up part of its oxygen to form water (H_2O) with the hydrogen, and became reduced to a lower oxide (Mn_2O_3). The manganese was mixed with fragments of carbon to increase the conductivity, and to hold more gas. The porous cup was found to increase the internal resistance of the cell, and the manganese dioxide was then mixed with carbon and cement to form blocks, which were then held against the carbon plate by means of rubber bands. The next step was to make the carbon in the form of a hollow cylinder, and place the depolarizer inside, as in the Samson (see Fig. 614) and the Hayden cells. In some cells the depolarizer is mixed with the carbon, and both are molded and baked into a solid mass; such cells do excellent work at first, but are apt to wear out quicker than those in which the depolarizer can be renewed. Many millions of sal ammoniac cells are used for operating bells and telephones.

617. *How strong should the solution be in a sal ammoniac cell?*

The directions vary with different cells, but about five ounces of the dry salt to one quart of water is an average solution. If the solution is too strong, a double salt of the chlorides of zinc and ammonium is liable to crystallize out and deposit on the zinc, thus increasing the internal resistance of the cell and also lowering its E.M.F.

618. *Why do the zincs in sal ammoniac cells usually eat through at the top faster than at the bottom?*

At the surface of the liquid there is more or less oxidation, but this does not explain the fact that the zinc becomes gradually thinner toward the top. There is generally more or less of the double chloride of zinc and ammonium present in every sal ammoniac cell. As this is heavier than the mixed solution of zinc chloride and of ammonium chloride, it settles toward the bottom of the cell. There is then a local action which tends to dissolve the zinc at the top and to deposit it at the bottom, for zinc in a solution of zinc chloride is positive to zinc in a solution of the double salt; the zinc and the liquid thus become a short-circuited cell.

619. *Why are zincs better when amalgamated?*

Commercial zinc is not chemically pure, but contains impurities such as bits of iron, carbon and other substances. When the zinc is immersed in any liquid which attacks the zinc more than the impurities, an E.M.F. is set up; as the two substances are connected through the liquid and also through the metal, local currents are set up which eat away the zinc until the foreign substance is set free and falls away. When the zinc is amalgamated, that is, coated or alloyed with mercury, the mercury seems to cover up the impurities and to bring only the pure zinc to the surface. The smooth surface seems to hold a film of hydrogen when the cell is not at work, and this film seems to protect the zinc from attack when acid is present, and to protect it from local action at all times.

620. *How are zincs amalgamated?*

A common way is to dip the zinc in dilute sulphuric acid, which cleans it thoroughly, and then to rub mercury over it with a swab until the zinc is uniformly bright all over. The swab may be simply a piece of cloth wrapped around a wooden stick. In some cases the zinc and mercury are cast into a sort of alloy or amalgam, the zinc being melted first and the mercury added.

621. *What is the silver chloride cell?*

This cell uses a zinc rod for positive electrode. The negative consists of a silver rod surrounded by silver chloride, which is melted into a cylinder upon the rod. The electrolyte is a solution of sal ammoniac. When the cell generates current, the zinc displaces the chlorine in the sal ammoniac, and the ammonium thus set free displaces the chlorine in the silver chloride, leaving metallic silver deposited on the silver electrode. No gas is set free unless the cell is worked too hard. This cell gives about 1.1 volts and, being small

and easily portable, is much used for testing purposes, and to some extent for medical purposes.

622. *What are dry cells?*

Dry cells are generally modifications of sal ammoniac cells, in which the water is largely replaced by some gelatinous substance of more or less secret composition. The original Gassner dry cell used a paste made of 1 part oxide of zinc, 1 of sal ammoniac, 3 of plaster, 1 of zinc chloride and 2 of water, all by weight. Dry cells are very convenient for portable use and in the hands of unskilled persons, but their useful life is generally much shorter than that of cells using solution of sal ammoniac in water.

623. *Why is it necessary to remove the zinc from some forms of open circuit battery when not in use?*

In some cells which use permanganate of potash or sulphuric acid in order to secure a high E.M.F., the electrolyte acts upon the zinc by ordinary chemical action, even when not delivering current; such cells are therefore provided with means for removing

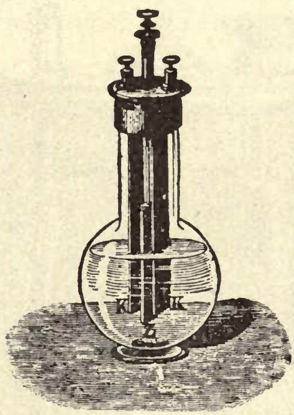


FIG. 623.—GRENET CELL.

the zinc when not in use. A "Grenet" cell of this type, illustrated in the figure, shows plainly the rod and clamp for raising the zinc plate in the center between the positives.

624. *Explain the action of the bichromate cell.*

The bichromate cell takes various forms, being commonly arranged so that the zinc or both elements may be lifted easily from the liquid. They are often called "plunge batteries," since the elements must be plunged into the solution before the current is generated. The liquid contains sulphuric acid (H_2SO_4) and chromic

acid (CrO_3). When the cell is in operation, the zinc is dissolved by the sulphuric acid, forming zinc sulphate ($ZnSO_4$), the hydrogen set free unites with the oxygen in the chromic acid to form water, and the chromium thus left unites with part of the sulphuric acid to form chromium sulphate ($Cr_2(SO_4)_3$). In this form of cell, the chromic acid is generally made when the cell is first set up, by pouring sulphuric acid (78.5 cu. cm.) into a solution of 77.5 grams of bichromate of potassium ($K_2Cr_2O_7$) in 750 cu. cm. of water; the acid and bichromate unite to form chromic acid and potassium sulphate (K_2SO_4). The latter unites with the chromic sulphate formed during the operation of the battery and forms a compact mass of crystals of chrome alum ($K_2Cr_2(SO_4)_4$). Sodium bichromate is often used instead of potassium bichromate in the proportion of 200 grams of sodium bichromate to 1000 cu. cm. of water and 150 cu. cm. of strong sulphuric acid, more acid being added as the battery becomes exhausted. Sometimes the chromic acid is used directly, being

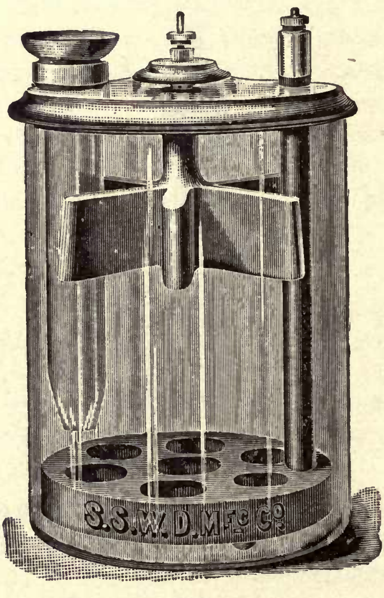


FIG. 624.—PARTZ CELL.

used in the proportion of 150 grams to 1000 cu. cm. of water and 150 cu. cm. of strong sulphuric acid. Any form of bichromate cell gives 2 volts when fresh. The Partz bichromate cell, which looks somewhat like the gravity cell (see No. 626), has a carbon element at

the bottom, a zinc element near the top, and a funnel through which fresh chemical salt is introduced as needed.

625. *Explain the Fuller cell.*

This cell, which is used to a large extent by telephone companies, is a modification of the bichromate cell, having an amalgamated zinc in a porous cup filled with a solution of common salt in water. The carbon is placed in the outside jar with a solution made of 6 ounces of sodium bichromate, 17 ounces of sulphuric acid and 56 ounces of soft water. A little mercury, placed in the bottom of the porous cup, keeps the zinc well amalgamated. There is said to be little local action and the cell works a month or more without attention.

626. *What are closed circuit batteries?*

In closed circuit cells it is usually necessary to keep the circuit closed all of the time to prevent injurious action in the cell, as it is harmed more by standing idle than by use. The best known example of a closed circuit cell is the gravity or "crowfoot" cell, used so largely for telegraph and fire alarm circuits. The zinc electrode is commonly cast in the form of a foot, which gives it the common

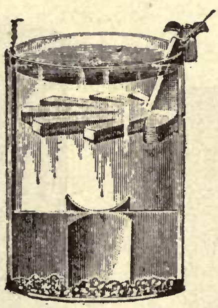


FIG. 626.—CROWFOOT CELL.

name. The copper positive plate usually consists of several sheets of copper riveted together and to an insulated wire, which forms the terminal. Crystals of copper sulphate, often called "blue vitriol" or "blue stone," are placed in the bottom and the cell is filled with water. As the cell stands, the copper sulphate dissolves in the water and the solution rises higher and higher until it reaches the zinc, unless the circuit is closed. In this cell the zinc is dissolved, forming zinc sulphate at the top of the cell, while copper is deposited from the blue solution upon the copper plates at the bottom. So long as the cell is working, there is a more or less distinct division between the two solutions, but if the cell is left on open circuit, the copper so-

lution rises until it comes into contact with the zinc, where the copper deposits and a local action rapidly eats up the zinc and exhausts the solution. As the copper solution is heavier than the zinc, it tends to stay at the bottom of the cell and gravity keeps the zinc and copper solutions apart when the cell is working. This gives it the name of "gravity cell."

627. *Are any cells suitable for both intermittent and continuous work?*

A storage cell is suitable for both kinds of work, provided not too long a period of idleness is imposed upon it, in which case the cell gets out of order and loses its charge. There are a few primary cells that are well adapted for continuous work, and also will stand idle without any deleterious action. One of the best known of these is the Edison-Lalande cell.

628. *Explain the action of the Edison-Lalande cell.*

In this cell the positive electrode is one or more plates of zinc and the negative electrode consists of a slab of copper oxide held in a

FIG. 628A.—GORDON CELL.

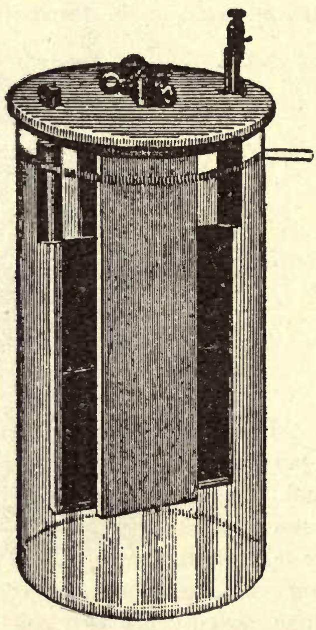


FIG. 628B.—EDISON LALANDE CELL.

frame of copper. The electrolyte is a strong solution of caustic soda (NaOH) or caustic potash (KOH). When the cell is working the zinc dissolves, forming sodium (or potassium) zincate

($Na_2 ZnO_2$), and displacing the hydrogen which moves with the current to the negative plate, where it unites with the copper oxide to form water (hydrogen dioxide, H_2O), and metallic copper. The solution is always covered with a layer of heavy paraffine oil, both to prevent evaporation and also to prevent the carbonic acid gas of the air from acting on the solution. When the oil is not used the life of the cell is reduced to about one-third. The Edison-Lalande cell gives about 0.7 volts. The Gordon cell is similar to the Edison-Lalande, except that the zinc is made into a cylinder surrounding the inactive element, which consists of a perforated tin cylinder filled with oxide of copper.

629. *Give an example of a cell with mechanical depolarizer.*

The Smee cell, formerly used to a considerable extent, is a good example. This had plates of zinc and of platinized silver immersed in dilute sulphuric acid. The platinized silver had a rough surface which facilitated the collection of the hydrogen into bubbles large enough to rise easily to the surface and so escape to the air. Carbon was found to be cheaper than platinized silver and also to give a higher E.M.F. The action of the cell is explained by saying that the zinc dissolves in the sulphuric acid ($H_2 SO_4$), forming zinc sulphate ($ZnSO_4$) and thus displacing the hydrogen (H_2) from the acid, which then collects in bubbles on the silver or carbon plate. When the action of the cell becomes weak from the collection of hydrogen bubbles, they can be removed by stirring the liquid or by lifting the plates from the cell. This cell gives 1 volt when fresh. The Smee cell was formerly used to a considerable extent for electroplating and for similar purposes requiring a strong current. A more common example of cell with mechanical depolarization is the sal ammoniac cell (see No. 615) used for ringing bells and similar intermittent work.

630. *What kind of cells use liquid depolarizers?*

These may be divided into two classes, those with single liquids and those with two. The former class is represented by the bichromate cells (see No. 624), the latter by the gravity (see No. 626), Daniell or Bunsen.

631. *Explain the action of the Bunsen cell.*

The Bunsen cell contains a carbon plate in a cup of porous earthenware filled with strong nitric acid (HNO_3). The zinc is placed in a jar outside the porous cup and filled with dilute sulphuric acid ($H_2 SO_4$) made of about one part of acid to twelve of water. A number of molecules of the sulphuric acid, H_2SO_4, seem to be

broken up into free hydrogen ions, H, and sulphions, SO_4 (see No. 644). When the cell is in operation, the sulphions appear at the zinc anode and form zinc sulphate, $ZnSO_4$, while the hydrogen ions appear at the carbon cathode, where they take part of the oxygen from the nitric acid to form water (H_2O) and leave nitrous acid (HNO_2), or hyponitrous acid (HNO); or, the hydrogen may even reduce the latter acid to nitric oxide (NO), which escapes as a very corrosive and objectionable gas. This cell gives about 1.8 volts.

632. *Explain the Daniell cell.*

The Daniel cell, formerly used as a standard of E.M.F., is somewhat similar to the Bunsen, in having one electrode within a porous jar, and in having two liquids. A common form has a zinc rod or plate within the porous jar, which is filled with zinc sulphate dissolved in water or with dilute sulphuric acid. The outer vessel contains a copper electrode and is filled with a solution of copper sulphate ($CuSO_4$), often called "blue vitriol" or "blue stone." When the cell is delivering current, part of the zinc sulphate breaks up into zinc ions and sulphions; the zinc ions displace copper ions from the copper sulphate solution and the displaced copper ions appear at the copper electrode and are deposited as metallic copper; the sulphions (see Nos. 631 and 644) appear at the zinc anode and form zinc sulphate. If sulphuric acid were used without the copper sulphate, the zinc in uniting with the acid would displace the hydrogen, which would then tend to collect at the copper. Instead of collecting in bubbles, however, the hydrogen displaces the copper from the copper sulphate, which thus becomes a sort of electro-chemical depolarizer.

633. *What governs the amount of current delivered by a battery of one or more cells?*

The current from a battery, like that from any other source, is governed by Ohm's law. (See Nos. 315 to 329). The current (measured in amperes) equals the E.M.F. (measured in volts) divided by the total resistance of the circuit (measured in ohms). This resistance includes the resistance in the external circuit, and also the internal resistance of the cells. If the resistance of the external circuit is high, as is the case with telegraph lines, the internal resistance of the cells is but a small part of the whole, and the cells are connected in series to give high E.M.F. If the external circuit is of low resistance, the resistance of a single cell may be high as compared with that of the external circuit. The internal resistance of a cell is less as the electrodes are larger and closer together; by con-

necting together similar electrodes of several cells, they all act as one large cell having much less resistance than any one, the combined resistance of several cells of similar size and construction being equal to that of one divided by the number of cells connected in multiple. Thus, if the resistance of one cell is 1 ohm, the resistance of five cells coupled in multiple is one-fifth of an ohm. Cases often arise where it is best to make a combination of series and parallel, connecting the cells in several sets having an equal number of cells in series and then connecting these sets in multiple. The greatest output is obtained when the resistance of the cells equals that of the line, but this is not the most economical arrangement, since half of the energy is then lost in the cells. For the highest economy, the internal resistance of the cells should be as low as practicable in comparison with the resistance of the external circuit.

634. *What is a gas battery?*

The simplest one is that of Grove, who arranged platinum electrodes so that each dipped into acidulated water and also was in contact with a gas. When one electrode was in hydrogen and the other in oxygen, he obtained nearly 1 volt. Many attempts have been made to develop a commercial battery from this, but none have been very successful. These cells give a high theoretical efficiency and may some day prove to be the basis of a more economical source of electricity than dynamos driven by steam or water power, but up to the present time they are simply a hope.

635. *What is a storage battery?*

A storage battery is a battery which, when exhausted, can be recharged by sending current through it from another source. The earliest note of this was a discovery by Gautherot, who found, in 1801, that silver or platinum wires used for decomposing water by the passage of an electric current would send a current in the reverse direction when the battery was removed. This was studied further by Ritter, De la Rive and Grove, who developed the gas battery. The modern storage battery is developed from the work of other experimenters with lead electrodes. Faraday, in 1834, found that lead peroxide (PbO_2) deposited by acetate of lead ($Pb(C_2H_3O_2)_2$) would give a current in the opposite direction from that originally causing the decomposition. In 1854, Sinsteden used plates of lead, silver and nickel in a voltameter and obtained reverse currents strong enough to heat a wire to incandescence. In 1860, Plante sent current through two sheets of lead, which were separated by canvas and immersed in acid, and he obtained a much more powerful and dura-

ble secondary current than had Faraday or Sinsteden, and he is generally looked upon as the discoverer or inventor of the storage battery. Plante found that the capacity of his lead secondary battery increased with use, finding that the surface of the lead was changed into sulphates and oxides and that these coatings became deeper and deeper with use. In 1881, Faure found that the oxide might be applied mechanically more cheaply than by forming from the plate, and his pasted cell came into extensive use.

636. *How are storage batteries made at present?*

For a number of years, the Faure process was used more generally, but at present it seems to be used comparatively little in America. The processes used by different manufacturers differ in

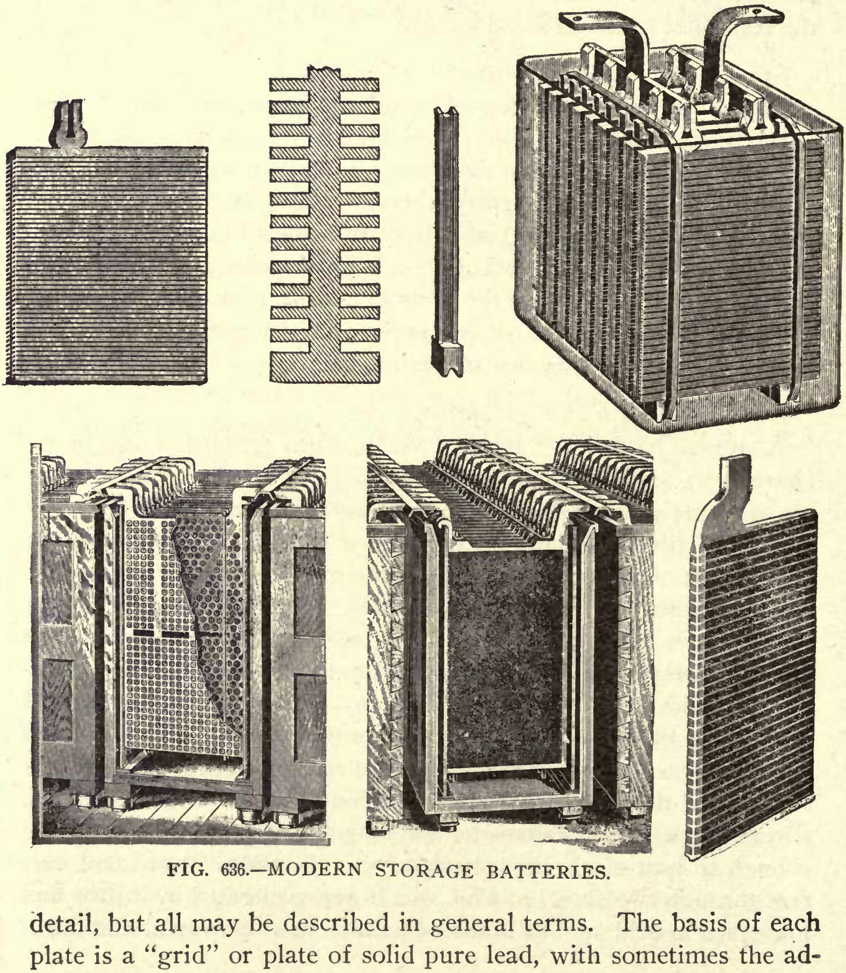


FIG. 636.—MODERN STORAGE BATTERIES.

detail, but all may be described in general terms. The basis of each plate is a "grid" or plate of solid pure lead, with sometimes the ad-

dition of a little antimony to make it harder. This plate is cast, rolled or cut into a shape that gives a large amount of surface, a common method being to make a series of parallel grooves. The grooves are then filled with active material, either by the mechanical application of lead oxide or by the action of acids which attack the surface of the metal until the interstices are filled with a spongy mass of lead oxide. After being thoroughly washed to remove the oxidizing solution, the plates are set up in a dilute solution of sulphuric acid ($H_2 SO_4$), often known as "oil of vitriol;" the alternate plates are connected and current is sent through from one set of plates to the other; current is then cut off and the plates are connected through a resistance so as to deliver current and become discharged; current is then sent through them again for a longer time and they are again discharged. After this operation has been repeated several times, the plates are formed and are ready for use. Small cells are sent out from the factory ready for filling with acid and for charging. For larger cells, such as used in central stations, the plates are entirely separate and are set up and connected where the battery is to be used. In a battery for central station use, all of the positive plates of one cell are "burned" or fused to a lead connecting strip, to which also are fused all of the negative plates of the next cell; in this way all of the cells are rigidly connected into one series. In smaller batteries it is common to have the corresponding plates of each cell fused to a common terminal strip, and the different cells are coupled by means of lead covered bolts, or, in some cases, by rubber covered flexible copper cables bolted to the lead terminals.

637. *Explain the action of the storage cell.*

The chemistry of the lead storage cell is somewhat complicated and physicists are not entirely agreed about what actually takes place. The most commonly accepted theory is as follows: When the cell is thoroughly charged, the positive plate is covered with lead per oxide (PbO_2), while the negative plate is covered with spongy metallic lead. (In speaking of storage batteries the positive plate is where the charging current enters and the discharge current leaves the cell). During the discharge, the lead at the negative plate unites with the sulphuric acid (H_2SO_4), forming lead sulphate ($PbSO_4$), and setting hydrogen free. At the positive plate, the lead peroxide (PbO_2) unites with the hydrogen set free from the negative plate and forms a lower oxide (PbO) and water; this lower oxide then unites with sulphuric acid and forms lead sulphate ($PbSO_4$) and water ($H_2 O$). As the cell becomes discharged, the acid thus

unites with the plates and water is formed, so that the density or specific gravity of the electrolyte falls from about 1.22, when fully charged, to about 1.18 when discharged to the lowest safe limit. When the cell is charged by the passage of current in the opposite direction, the above processes are reversed. When the voltage is allowed to fall below 1.8 volts per cell, the lead sulphate is liable to change into an insoluble form, which reduces the capacity of the

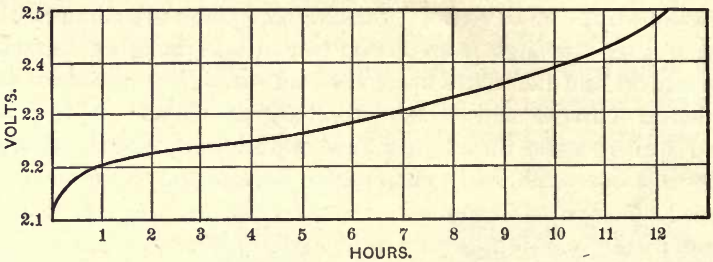


FIG. 637A.—CHARGING CURVE.

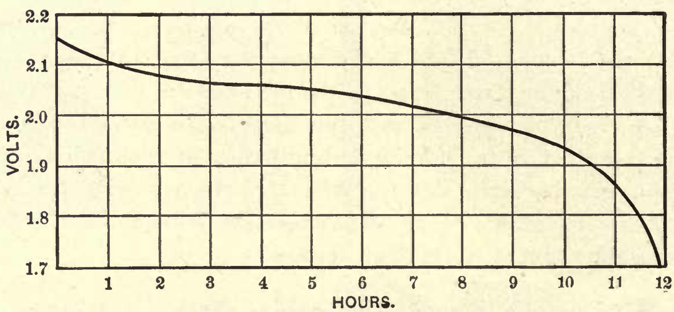


FIG. 637B.—DISCHARGING CURVE.

cell, and the cell is then said to be "sulphated." Care should therefore be taken not to allow the battery to become discharged too far. When the cell is being charged, the necessary voltage rises from 2.2 volts to about 2.5 volts per cell. When the cell is fully charged, the further application of current breaks up the water of the solution, liberating hydrogen gas at the negative and oxygen gas at the positive. These gases reduce the amount of the solution in the cell, both by the decomposition of the water and by the acid which is carried off in spray by the gases. This spray is also carried off if the charging current is too strong, so that the active material on the electrodes is affected at the surface much faster than nearer the center of the plate. On the other hand, if the charging current is less than about one-fifth of the normal current, the insoluble sulphate is

apt to form and so injure the plates. The normal rate of charging is about 8 amps. per square foot of total surface of the positive plates. If the cell is charged or discharged too fast, the action is liable to be unequal on different parts of the plates, and so to cause the plates to bend or "buckle," since the active material expands during discharge.

638. *How is a storage battery charged?*

Storage batteries are almost always charged from dynamos giving nearly constant E.M.F. When only a few cells are to be charged, they may be connected across a continuous current incandescent lighting circuit, enough lamps being in series with them to give the desired current. When a battery of fifty or more cells is to be charged, connection is made directly with the dynamo. In beginning the charge, the dynamo should be adjusted to give from 2 per cent to

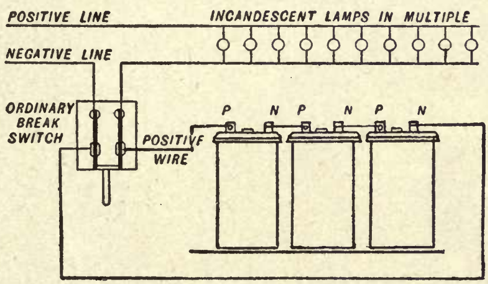


FIG. 638.—CHARGING BATTERY FROM INCANDESCENT LIGHTING CIRCUIT.

5 per cent higher E.M.F. than that of the batteries. Both terminals of the dynamo should then be connected to the corresponding terminals of the battery, positive to positive and negative to negative. After a half hour or so, the voltage of the dynamo may be raised so as to increase the charging current to the normal amount, and then when the battery begins to gas, its voltage will have risen enough to reduce the current. In central station practice, where the same dynamos must supply current to the lines at constant voltage and at the same time charge a battery, it is necessary to provide means for obtaining two different voltages. When the current required on the lines is small compared with that required by the batteries, the voltage of the dynamo may be adjusted to that required by the batteries, and an adjustable resistance may be inserted in the main line to reduce the line voltage to that required by the circuit. This is commonly done on railway trains, where the dynamo sometimes charges the batteries and at the same time furnishes current for lighting the

lamps. On the other hand, when the battery is a smaller part of the entire load, provision is often made for an auxiliary dynamo to raise the voltage of the current used for charging the battery. Such a

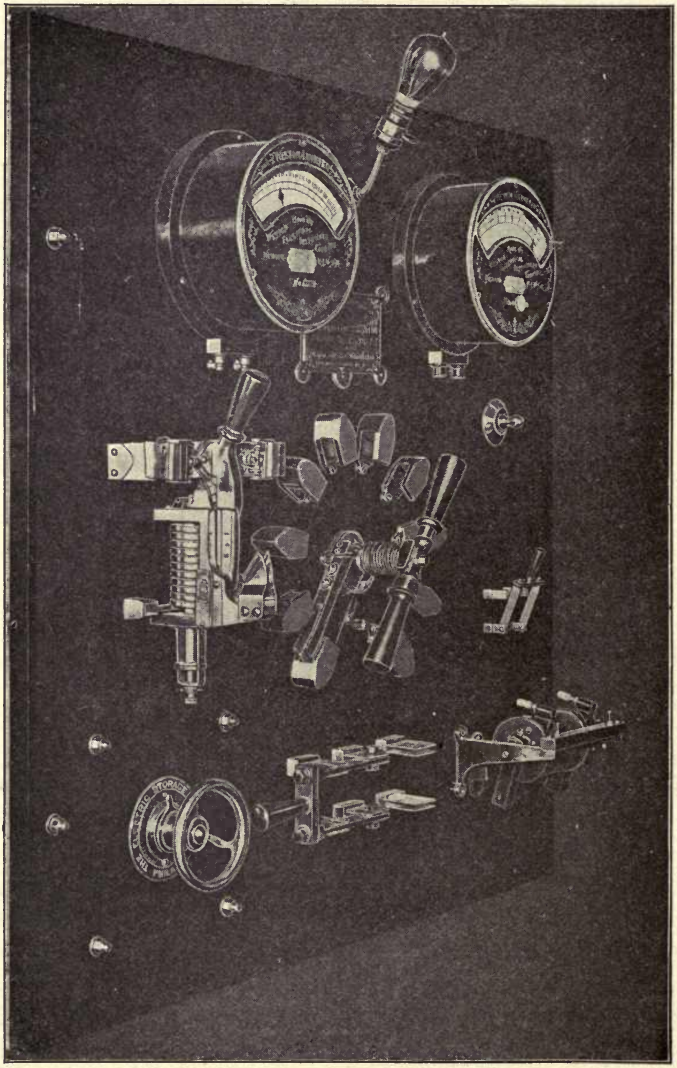


FIG. 638B.—BATTERY SWITCHBOARD FOR ISOLATED PLANT.

dynamo is called a "booster," and may be driven by the same power that operates the main dynamos, although it is more often driven by an electric motor. The battery is usually connected with the booster through end cell switches.

639. *How can the positive and negative terminals of a battery or dynamo be distinguished?*

In the storage battery the positive plates have a brownish or chocolate appearance, while the negative plates are gray or slate colored. The polarity of a battery or dynamo may be tested (as explained in No. 311) by connecting the terminals to two pieces of lead or other metal dipped in water which has a slight amount of acid; bubbles of gas will appear at both pieces, there being the most at the terminal connected with the negative terminal of the battery or dynamo. If the test metals are of lead, the piece connected with the positive terminal will become coated with a brown deposit, and that connected with the negative terminal will become gray or slate colored. An easier method of determining polarity is to use a voltmeter of the permanent magnet type and having its terminals marked; if the positive terminal of the battery is connected with the positive terminal of the voltmeter and the negative to negative, the voltmeter needle will be deflected in the right direction, otherwise it will move backward. The chemical paper or potato test (see Nos. 312 and 313) is also convenient.

640. *How can one tell whether a storage battery is working properly?*

Experience counts for much in such work. The appearance of the plates is a good indication of the condition of the battery. When the color is uniform and of the proper gray and brown shades, the battery is probably all right. The acid should be tested with a hydrometer occasionally to see that the solution is of the right strength, not less than 1.15 when the battery is discharged, and not more than 1.27 when it is fully charged, and it should be adjusted by the addition of dilute acid or of clear water, as the case requires. The standard density of electrolyte for any given battery is generally specified in the printed directions. The solution should always cover the plates ½ in. or more. The cells should not be allowed to discharge lower than 1.8 volts per cell, and in charging the pressure should not be carried higher than 2.5 volts or 2.6 volts per cell. If one cell is found to give lower voltage than others, it is probably caused by some foreign substance falling into the cell and bridging across from positive to negative plate and so discharging the cell, or changing the acid. Any metal falling into the liquid will be dissolved and secondary actions will be apt to injure the cell. Sometimes the active material or sulphate shed from the plates is allowed to collect at the bottom of the cell to such a depth as to touch the

plates and so cause a local circuit which will discharge the cell. Such a cell should be cleaned and then fully charged by itself. If the plates become covered with a whitish scale, the cell has "sulphated" from being discharged to too low voltage, or from the acid being too strong; this reduces the capacity of the battery and may be removed by charging the cells for a longer time than usual, making them boil for some time until the plates resume their normal color. The makers will generally supply full instructions for the care of their cells.

641. *How is the current from a battery regulated?*

Batteries are generally designed to supply a circuit at constant E.M.F., and the current is then controlled by the resistance of the line and attachments. As the battery becomes discharged, its pressure gradually drops off. The curve in Fig. 637b shows how the pressure drops when the discharge current is kept constant at the

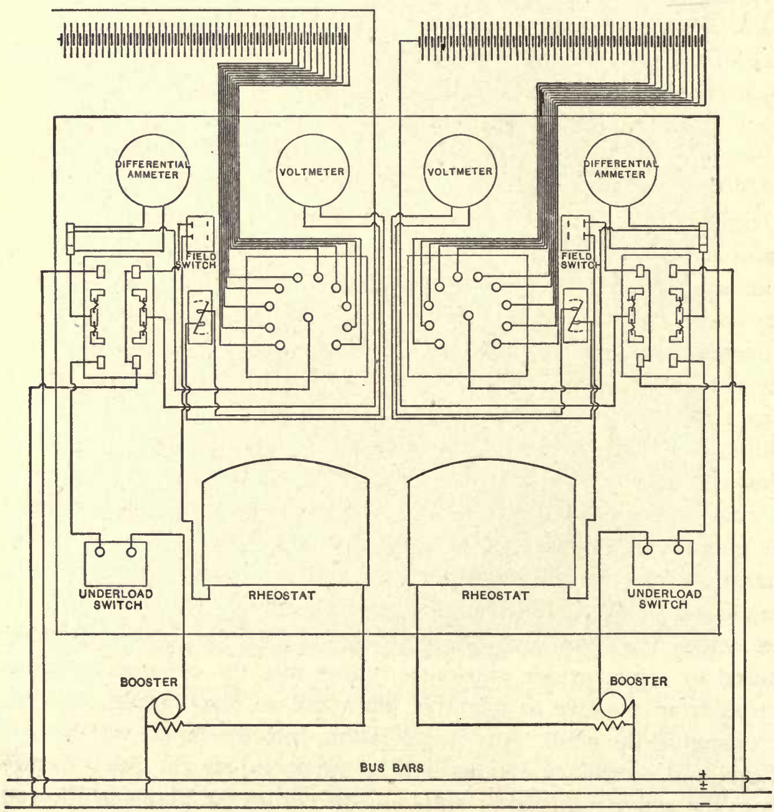


FIG. 641.—DIAGRAM OF SWITCHBOARD FOR STORAGE BATTERY ON THREE-WIRE SYSTEM.

normal capacity of the battery. In central station batteries it is usual to provide enough cells to supply the required voltage when all are discharged down to the safe limit of 1.8 volts per cell. The cells at one end are provided with terminals leading to a switch, so that the total number of cells in the working circuit may be varied at will. At the beginning of the discharge, when all the cells are fully charged and each cell furnishes about 2.2 volts, it takes only fifty cells to furnish 110 volts; but as the cells discharge, their voltage falls, and it is necessary to move the "end cell" discharge switch so as to cut in another cell. A new end cell is then cut in for each drop of two volts in the total pressure. Since these end cells are in use a shorter time than the main battery, they become charged sooner and it is necessary to have also an end cell charging switch. At the beginning of the charge, all of the end cells are in circuit; the one on the end was discharging for the shortest time, and so it becomes fully charged before any others, and should be cut out of the circuit; the next cell likewise becomes charged soon and is cut out, and so on with all of the end cells until at the end of the charge only the cells of the main battery are in circuit. By having separate end cell switches for charging and for discharging, it is possible to keep the battery connected with the main circuit both while it is charging and while it is discharging. In the case of batteries for lighting railway trains and for some other purposes, there is no need for end cells, since the load on the battery is usually greatest at the early evening when the battery is fully charged and drops off as the battery discharges. In telephone exchanges, the battery should be kept well charged, so that the discharge never reaches the part of the curve where the pressure drops rapidly.

642. *For what purposes are storage batteries used?*

They are used largely for replacing the more expensive primary cells formerly used for operating telegraph, telephone, fire alarm and police systems, for operating small motors, medical coils and similar portable apparatus, for operating motors and lights on automobiles, cars and boats; for steadying fluctuating loads on central stations and isolated plants for furnishing light and power; for increasing the maximum capacity of dynamo plants operated by steam or water power; to furnish a reserve power for emergency. Storage batteries will return from 40 per cent to 80 per cent of the energy supplied in charging, and thus are valuable auxiliaries in electric power plants where the load varies through wide limits, the batteries being

charged when the load is small and when charging power can be developed at little additional cost, and supplying current when the load is greatest and when the value of additional power is highest. When the load fluctuates rapidly, as is the case with street railways

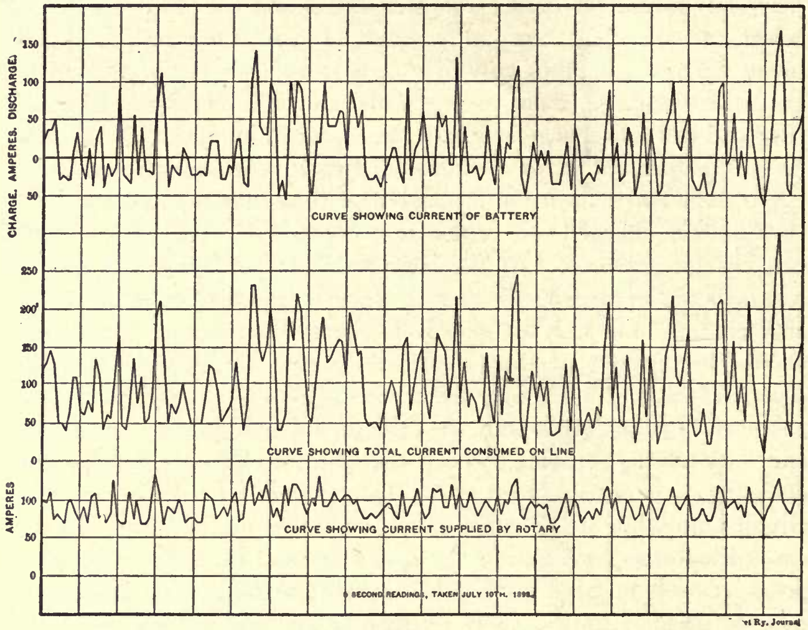


FIG. 642.—CURVES SHOWING REGULATING EFFECT OF STORAGE BATTERIES.

and electric elevators, the battery acts as a sort of fly-wheel, taking a charge when the load is small and the pressure high, and delivering current when the load is heavy and the pressure drops. The accompanying curves illustrate such action of a battery.

643. *In what ways does electricity cause chemical action?*

As noted in No. 600, the current may cause chemical action directly by electrolysis, or indirectly by its heating effect. An electric current has no chemical effect while passing through a solid conductor; when current passes through any liquid conductor other than an elementary substance, such as a melted metal, the liquid is decomposed and chemical action appears at one or both electrodes. Gases do not seem to conduct current as it is supposed to flow in a solid conductor, but rather carry electricity by convection, the atoms or ions carrying positive and negative charges between the

electrodes. (See No. 644). In some cases, especially where the gases are hot, there seems to be an electrolytic action similar to that occurring in liquids, causing the combination or separation of atoms to form new compounds.

644. *What is an ion?*

All substances are composed of very minute particles known as molecules, which in turn are composed of still smaller elementary particles called atoms. Until recently the molecule has been looked upon as being the smallest particle of matter that could exist alone or in a free state, the atoms never remaining free, but always uniting with other atoms of the same or of different elements, so as to form molecules. Recent physical investigations indicate that in every solution there exist members of free atoms or groups of atoms smaller than molecules, which are called ions. The ions tend to appear at the electrodes, those at the anode being called anions; those at the cathode being called cations. Each ion is believed to carry a static charge, by which it is attracted to the oppositely charged electrode. A theory which is now coming into general acceptance is that, in the case of elementary gases, the passage of an electrical discharge breaks up the atoms, which have heretofore been considered as the ultimate particles of matter, into positive and negative ions, the negative ion being only a small chip forming about one one-thousandth part of the original atom, while the remainder of the atom becomes the positive ion; each of these charged particles may gather around itself a number of molecules and travel toward the electrode. Thus, in an elementary gas, such as hydrogen or oxygen, an ion may be a small chip of an atom, or the remainder of the atom, or either of these together with a group of other attracted molecules. In general, an ion may be said to be a small charged particle of matter. Many recent investigations strengthen the theory that all " elements " are modifications of one fundamental unit which is electricity.

645. *What is electrolysis?*

Electrolysis is the decomposition of conductors by the passage of current, occurring at the surface in contact with the liquid conductor. When the liquid contains a metallic compound in solution, the metal is usually deposited on the cathode and the remaining part of the compound is deposited at the anode. The general rule is that metals travel with the current. In many cases there are secondary reactions, so that the ions, originally liberated by the current, form other combinations before they can be secured at the electrodes. In many cases electrolysis is undesirable and would be

prevented if practicable, as in the case of damage to underground metal pipes by railway currents.

646. *What are the laws of electrolysis?*

(1.) The amount of chemical action is equal at all parts of a circuit; that is, the chemical action is independent of the location in the circuit, provided the current is equal in all parts.

(2.) The amount of an ion liberated in a given time is proportional to the strength of the current.

(3.) The amount of an ion liberated at an electrode in one second is equal to the strength of the current multiplied by the "electro-chemical equivalent" of the ion.

The first two laws mean that the chemical effect produced is proportional to the quantity of current multiplied by the time, so that 10 amps. acting for one hour produce the same result as 5 amps. acting for two hours. Explanation of the third law involves some chemical knowledge of the elements. The second and third laws are named after their discoverer, Faraday.

647. *What is meant by the "electro-chemical equivalent?"*

The electro-chemical equivalent of an element is the amount liberated by one coulomb. Experiment shows that one coulomb (1 amp. flowing for one second) will liberate 0.000010384 grams of hydrogen from water or other compound. As hydrogen is the lightest element known, its weight is taken as unity, or the basis of comparing the weights of atoms of other elements. The various elements are also classified according to their "valency," or the power they have of uniting with other elements. Thus one atom of oxygen will unite with two atoms of hydrogen to form one molecule of water (H_2O), and oxygen is, therefore, said to be a dyad or to have a valency of two. Other elements have a valency of one, two, three, or even four. The electro-chemical equivalent of an element is therefore the atomic weight multiplied by 0.000010384 and divided by the valency.

648. *Explain the table of electro-chemical equivalents.*

The table gives a list of the more common elements arranged alphabetically. The second column gives the abbreviation used for each element. The third column gives their valency, that is, the number of atoms of hydrogen or other monad element with which one atom of the element will unite. The fourth column gives the atomic weights of the elements, taking the weight of hydrogen as a unit. The fifth column gives the chemical equivalent, which equals the

atomic weight divided by the valency. The sixth column gives the electro-chemical equivalent, that is, the number of grammes of each element that would be liberated from a compound by 1 amp. of current acting for one second. The seventh column gives the number of grammes liberated by 1 amp. acting for one hour, this being equal to 3600 times the amount liberated in one second. The eighth column gives the number of pounds of each element liberated by 1 amp. acting for one hour. The ninth and tenth columns give the number of ampere-hours necessary to liberate 1 lb. or 1 kg. In all of the cases it should be remembered that the ampere-hours are the product of current by time, and may be made up of any number of amperes multiplied by the corresponding number of hours.

ELECTRO-CHEMICAL EQUIVALENTS

Element	Symbol	Valency	Atomic Weight.	Chem. Equiv.	Electro Chemical Equivalent.	Grammes per Ampere Hour	Pounds 1000 Ampere Hours	Ampere Hours per Pound	Ampere Hours per Kilo
Aluminum	Al	3	27.5	9.1	.0000945	0.339	0.745	1333.	2950.
Antimony	Sb	3	122.	40.66	.000414	1.490	3.285	304.	671.
Arsenic	As	3	75.	25.	.000259	0.932	2.055	487.	1073
Barium	Ba	2	137.	68 5	.000709	2.552	5.627	178.	392.
Bismuth	Bi	3	210.	70.	.000725	2.608	5.75	174.	383.
Boron	B	3	31.	10.33	.000107	0.385	0.849	1179.	2598.
Bromine	Br	1	79.8	79.75	.000828	2.982	6.59	152.	335.
Cadmium	Cd	2	112.	55.8	.000578	2.079	4.58	218.	481.
Calcium	Ca	2	40.	19.95	.000207	0.744	1.64	610.	1343.
Carbon	C	4	12.	3.	.000031	0.112	0.241	410.	8950.
Chlorine	Cl	1	35.4	35.37	.000367	1.322	2.915	343.	756.
Chromium	Cr	6	52.5	8.75	.000091	0.326	0.720	1390.	3068.
Cobalt	Co	2	58.8	29.3	.000305	1.099	2.42	413.	910.
Copper (cuprous)	Cu	1	63	63.	.000654	2.355	5.192	193.	425.
" (cupric)	Cu	2	63.	31.5	.000327	1.178	2.596	385.	849.
Fluorine	F	1	19.	19.	.000197	0.708	1.562	640.	1413.
Gold	Au	3	196.2	65.4	.000679	2.445	5.391	186.	409.
Hydrogen	H	1	1.	1.	.00001038	0.037	0.082	12130.	26750.
Iodine	I	1	126 5	126.53	.001314	4.730	10.43	96.	211.
Iron (ferrous)	Fe	2	55.9	27.95	.000290	1.045	2.304	434.	957.
Iron (ferric)	Fe	3	55.9	18.63	.000194	0.697	1.536	651.	1436.
Lead	Pb	2	206.4	103.2	.001072	3.858	8.506	118.	259.
Lithium	Li	1	7.	7.	.000072	0.261	0.575	1739.	3830.
Magnesium	Mg	2	23.9	23.94	.000124	0.448	0.987	1014.	2235.
Manganese	Mn	3	55.	18.27	.000189	0.581	1.283	779.	1722.
Mercury (ous)	Hg	1	199.8	199.8	.002075	7.469	16.47	61.	134.
" (ic)	Hg	2	199.8	99.9	.001037	3.735	8.234	122.	268.
Nickel	Ni	2	58 6	29.3	.000304	1.085	2.415	414.	913.
Nitrogen	N	3	14.	4.67	.000049	0.175	0.385	2598.	5728.
Oxygen	O	2	16.	7.98	.000083	0.298	0.658	1520.	3352.
Phosphorus	P	3	31.	10.3	.000107	0.384	0.849	1178.	2604.
Platinum	Pt	4	197.	49.25	.000510	1.832	4.040	248.	546
Potassium	K	1	39.	39.04	.000405	1.459	3.218	311.	685.
Silicon	Si	2	28.	14.	.000145	0.522	1.15	870.	1918.
Silver	Ag	1	107.7	107.66	.001118	4.025	8.873	113.	249.
Sodium	Na	1	23.	22.99	.000239	0.860	1.895	528.	1184.
Sulphur	S	2	32.	16.	.000166	0.596	1.315	760.	1677.
Tin (stannous)	Sn	2	117.8	58 9	.000612	2.202	4.854	206.	454.
" (stannic)	Sn	4	117.8	29.45	.000306	1.101	2.427	412.	908.
Zinc	Zn	2	64.9	32.45	.000337	1.213	2.674	374.	824.

$$\text{Electro-chemical equivalent} = \frac{\text{atomic weight}}{\text{valency}} \times 0.000010384.$$

$$\text{“} \qquad \text{“} \qquad = \text{grammes per coulomb.}$$

$$\text{“} \qquad \text{“} \qquad = \text{grammes per ampere-second.}$$

$$\text{Pounds per 1000 amp.-hours} = \text{grm. per coulomb} \times 3600 \times \frac{1000}{453.4}$$

$$\text{“} \quad \text{“} \quad \text{“} \qquad = \text{el. chem. equiv.} \times 7938.$$

649. *What are the laws of electrolytic action other than those of Faraday?*

(4.) Liberated ions appear at the electrodes only.

(5.) Every electrolyte is decomposed into two portions, an anion and a cation, which may be themselves either elements or compounds. Thus water (H_2O) is decomposed into hydrogen and oxygen; but when current is sent through a solution of copper sulphate ($CuSO_4$), copper is liberated at the cathode, while the "sulphion" (SO_4) travels to the anode, with which it usually unites to form a sulphate.

(6.) In binary compounds (those composed of two elements) and most metallic solutions, the metal is deposited at the cathode; thus in electroplating, the object to be plated is made the cathode.

(7.) Aqueous solutions of salts of the alkaline metals (potassium, sodium, lithium, cæsium, rubidium and ammonium) and of the alkaline earths (calcium, barium and strontium) deposit no metal, but evolve hydrogen owing to the secondary action of the metal upon the water. Thus, when current is sent through a solution of common salt ($NaCl$) in water, chlorine gas is given off at the anode; but instead of metallic sodium appearing at the cathode, it unites with the water as fast as liberated from the salt and forms sodium hydrate ($NaOH$) or caustic soda, and in turn liberates hydrogen, which escapes as a gas.

(8.) Metals can be arranged in a definite series according to their electrolytic behavior, the more oxidizable metals being more strongly electro-positive, but the order varies with the nature, strength and temperature of the solution used (see No. 602). Each metal, when electrolyzed from its compound, behaves as a cation in preference to one more electro-negative. This is the basis of methods of electrolytic refining of metals, such as copper. On the other hand, alloys, such as brass, may be deposited electrolytically by using solutions such that the component metals dissolve with equal E.M.F's.

(9.) Several metals will be deposited at once from a solution of mixed salts, if the current strength is so great that the solution near the cathode becomes weak. For example, in refining copper, the silver and other impurities remain in the solution while the copper

alone is deposited, unless the current strength increases or the amount of copper in the solution near the cathode becomes weak in copper, when the greater resistance causes so high difference of potential that the silver is deposited with the copper on the cathode.

(10.) For each electrolyte a minimum E.M.F is requisite, without which complete electrolysis will not occur, though temporary polarization may exist. In such a case, a small current may flow for a short time, but the polarization immediately causes a counter E.M.F., which stops the further passage of current. (See, however (11), below.)

(11.) When both electrodes are of the same metal in their own salt, there is no opposing E.M.F., since no net chemical work is done, and the smallest E.M.F. will effect deposition. For example, in the Edison chemical meter, electrodes of amalgamated zinc are immersed in a solution of zinc chloride and connected around a shunt of low resistance. The current divides between the shunt and the "bottle," and a definite proportion of the total current passing through the electrolytic cell transfers a definite amount of zinc from the anode to the cathode, no net chemical work being done as the zinc is simply transferred from one plate to the other. This also is important in electrolytic refining of metals.

(12.) Where the ions are gases, pressure affects the conditions but slightly. Thus, 1 amp. passing through acidulated water liberates 0.0000103 grams of hydrogen each second, no difference whether the hydrogen escapes into the open air or into a vacuum or into a receiver under the pressure of many pounds per square inch. The E.M.F. necessary to effect decomposition increases to some extent with the pressure on the gas, but the given current liberates the same weight of gas in any case.

(13.) The chemical work done in a cell is proportional to the minimum E.M.F. necessary for polarization, and any additional E.M.F. simply represents the energy used in heating the cell.

(14.) Ohm's law holds good for electrolytic conduction. Thus, the resistance of a cell varies directly with the distance between the electrodes and inversely with their size. The total E.M.F. necessary for deposition consists of two parts, one equal to the E.M.F. of polarization and the other equal to the product of current by ohmic resistance of the cell.

(15.) Secondary reactions may result in (a) the ions decomposing, as SO_4 may decompose into SO_3 and O; (b) the ions reacting on the electrodes, as in the case of storage batteries; (c) the ions being liberated in an abnormal state, as when oxygen is set free in the state of ozone.

(16.) An electric current sometimes seems to act as a directing force to set in operation chemical forces previously latent. Thus, the damage to underground pipes seems in some cases to be due only secondarily to the electric currents from the street railways which put into action chemical forces latent in the soil.

650. *How much work is required to send current through an electrolyte?*

The work consists principally of three parts, although there may be other sources of small losses when the electrolyte is not of uniform density. Part of the work appears as heat, corresponding to the resistance loss in a metallic conductor, being equal to the product of current by the true resistance of the electrolyte. A second loss occurs at the surfaces of the electrodes where the molecules are rearranging themselves, a process called "sweeping" which represents an actual loss; the work lost in sweeping increases very rapidly for a few minutes when the current first begins to pass, and then is proportional to the strength of the current. The third part of the work is that done in effecting the chemical changes in the electrolyte, and is strictly proportional to the current; the chemical work causes an E. M. F. which is independent of the strength of the current and depends upon the chemical changes that occur; when this E. M. F. is in a direction to increase the current, the electrolytic cell becomes a battery; when it tends to reduce the current, it is called a counter-electromotive force.

651. *What is meant by polarization in an electrolyte?*

The polarization is the cause of the C. E. M. F. just mentioned. It may be transient, so that it disappears when the current ceases, or it may be permanent and be capable of causing a current to flow after the former main E. M. F. is removed. The most striking example is the storage battery which is "charged" by the current from some other source and later becomes itself a secondary source of current.

652. *Does polarization always occur when current passes through an electrolyte?*

Polarization always occurs when there is any net chemical work done. When both electrodes are of the same metal and the electrolyte is a "salt" or compound of that same metal, the current simply transfers metal from one plate to the other; there is no net chemical work done and no polarization occurs. This fact is the basis of the Edison chemical meter and some other voltameters.

653. *Is polarization a desirable phenomenon?*

In many instances it is undesirable, in others it is the foundation upon which the application of electricity is made. In the battery or chemical cell for generating electricity one polarization causes the E. M. F., while another may introduce an undesirable resistance. Polarization is closely identified with most of the electro-chemical processes of manufacture.

654. *Where can further treatment of electrochemistry be found?*

"Practical Electrochemistry," by B. Blount; "Notes on Electrochemistry," by F. G. Wiechmann; "Experimental Electrochemistry," by N. M. Hopkins; "Radioactivity," by E. Rutherford; "The New Knowledge," by R. K. Duncan; "Primary Batteries," by H. S. Carhart; "Primary Batteries," by W. R. Cooper; "Storage Battery Engineering," by L. Lyndon; "Electric Smelting and Refining," by W. Borchers and W. G. McMillan. See also sections on "Electrochemistry" in "Standard Handbook for Electrical Engineers," and in Foster's "Electrical Engineer's Pocket Book."

CHAPTER VI.

MAGNETISM.

700. *What is the relation between electricity and magnetism?*

Magnetism is sometimes considered as one form of electricity, that is, electricity in rotation. (See Nos. 4 and 8.) It is believed that all magnetism is due originally to the action of electric currents.

701. *What is the difference between magnetism and electro-magnetism?*

Electro-magnetism generally refers to magnetic fields that are maintained by the more or less continuous action of electric currents.

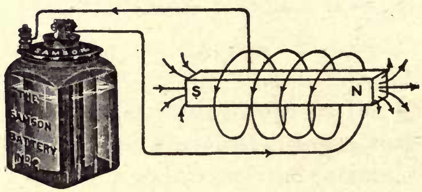


FIG. 701.—A SIMPLE ELECTROMAGNET.

Magnetism is a more general term and sometimes refers to magnetic fields existing without the immediate influence of current.

702. *What is meant by a magnetic line of force?*

The term is used either to indicate the direction of the force or as a measure of the strength of the magnetic field. The lines of force are considered as coming out from the north pole of a magnet (the end that would point toward the north if free to turn), and as returning into the south pole. (For the value of the line of force as a unit of magnetic measurement, see Nos. 241 to 246.)

703. *What connection is there between a current and a magnet?*

A magnetic field exists around a current, much like that about a magnet.

704. *What is meant by a magnetic field?*

This can be illustrated by a simple experiment. Scatter iron filings or chips upon a piece of glass or cardboard placed over a magnet, and then strike the cardboard gently. The filings will gradually

arrange themselves in well-defined lines, somewhat as shown in the figure. The arrangement of the iron particles shows that there

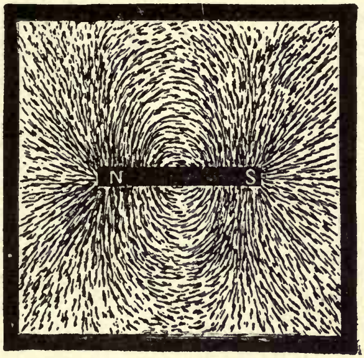


FIG. 704.—FIELD OF FORCE AROUND BAR MAGNET.

is some sort of force in the space around the magnet, a force that acts in well-defined directions and that is strongest near the poles or ends of the magnet. If a compass needle or a magnetized steel needle suspended by a hair or thread is moved about near the magnet, it will point in the direction of these lines, showing that there is a field of force all around.

705. *How can it be shown that there is a magnetic field due to the current?*

A simple way to show that the current is surrounded by a magnetic field is to bring a compass needle near a wire that is carrying a current. If the wire is horizontal, and the needle is placed over or under the wire, it will be rotated by the current and will stand about at right angles to the wire (the wire should run north and south, so that the needle would naturally be parallel to the wire). If the wire is vertical, the needle will turn so as to be tangent to the wire. If

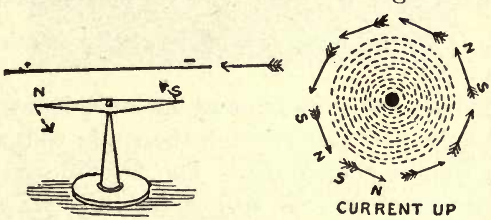


FIG. 705.—MAGNETIC NEEDLE DEFLECTED BY CURRENT.

the needle is moved around the wire, it will take different positions with its axis always tangent to a circle. A current of 10 amp. is strong enough to show these effects easily.

706. *How can the magnetic field about a current be shown by iron filings?*

Pass a wire vertically through a card or smooth board upon which iron filings or small chips have been sprinkled. Send a current of about 20 amp. through the wire, and at the same time slightly jar the card so that the iron bits can move easily. They will gradually

FIG. 706.—MAGNETIC FIELD AROUND CURRENT.

arrange themselves in more or less perfect circles, as shown in the figure. If one can not easily get a current of 20 amp., he can get almost as good results by passing the wire through the hole several times, making a coil of large diameter so that the returning wires will not affect the field seriously. With practice and care in selecting iron bits of the right size, one can obtain clearly defined circles about the wire.

707. *Why is there a clear space close around the wire where there are no iron bits?*

Near the wire the field is so strong that the iron bits are drawn to the wire and so leave the space clear for some little distance away.

708. *How is the magnetic field about a wire affected by forming the wire into a coil?*

Some of the lines will still surround the individual wires, but most of them will unite and pass through the entire coil, as seen in the figure, taken from a photograph. The field is seen to be strong through the center of the coil, so that the iron bits arrange themselves in quite definite lines, while outside the coil, the field is more scattered and is not strong enough to collect the iron bits into so definite lines. It is seen that the magnet field is strengthened by the current in each wire; in fact, if the wires are close together, the

total strength of field is proportional to the product of the current by the number of wires. A coil is sometimes called a solenoid

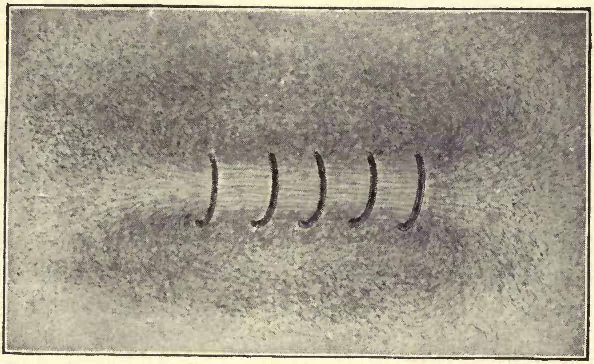


FIG. 708.—MAGNETIC FIELD OF SOLENOID.

or helix. When the coil is bent so its axis or core forms a closed circuit, the coil is called a torus.

709. *What sort of field exists between the poles of a magnet?* The lines of force go from one pole to the other in nearly straight lines. Between parallel surfaces the lines are straight. The lines of force beyond the parallel surfaces are curves, somewhat as shown

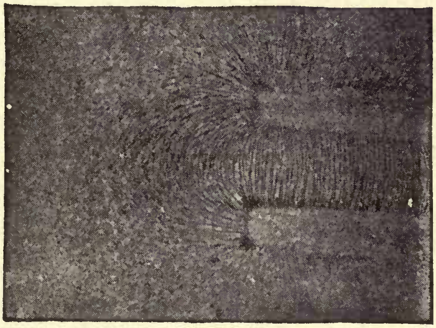


FIG. 709.—FIELD BETWEEN POLES OF A MAGNET.

in the figure. The magnetic force becomes less and less intense as the distance from the magnet increases, as shown by the lines of iron particles being less and less distinct.

710. *What reason is there for believing that the lines of force tend to follow the easiest path possible?*

This is a conclusion from the facts that particles of iron are drawn

into the magnetic field; that the magnetism is much stronger when its path is largely or entirely through iron; and that the lines tend to become as short as possible.

711. *How can it be shown that the lines of force tend to become as short as possible?*

This is illustrated by the well known phenomena of attraction, as when a magnet attracts its keeper. Familiar examples are the telegraph sounder and the electric bell.

712. *How is the attraction of unlike poles and the repulsion of like poles explained?*

There is no complete explanation agreed upon, although all the actions can be referred to simple laws. There is a tension along the lines of force and a pressure at right angles to them; in other words, the lines tend to shorten and to spread apart with a definite and known force.

713. *With how much force do the magnetic lines tend to spread apart?*

The spreading force measured in dynes equals gausses divided by 8π or multiplied by 0.04. (See Nos. 208, 242, 246.)

714. *With how much force do the lines tend to contract or shorten?*

The contractile, measured in dynes, equals gausses multiplied by 0.04, similar to the spreading force.

715. *How can one calculate the force with which a magnet attracts another magnet or a piece of iron?*

The force between the two equals the area of the common surface multiplied by the square of the number of lines of force per square centimeter divided by 25.14, or multiplied by 0.04.

$$\left(P = \frac{B^2 A}{8\pi} = 0.04\ B^2 A\right)$$

For example, suppose two pieces of iron 1 cm. square and of any convenient length are bent into half circles, and that the current is sent through a coil of wire wound about one or both pieces so as to magnetize the iron to a saturation of 5000 lines per square centimeter; the force at each joint between the two parts of the ring will be

$0.04 \times 1 \times 5000 \times 5000 = 0.04 \times 25{,}000{,}000 = 1{,}000{,}000$ dynes; the total force will be the sum of that at the two joints, or double that at one; hence, the total pull is 2,000,000 dynes. Since 981 dynes

equal the weight of 1 grm., the total pull between the two pieces is

$$2{,}000{,}000 \div 981 = 2024 \text{ grm.},$$

or about 4.4 lbs.

716. *How can this rule be modified for English measures?*

Four hundred fifty-three and six-tenths grammes equal one lb. Hence, if the dimensions and saturation are given in centimeters, the pull (in pounds) at each pole equals the area multiplied by the square of the number of lines per square centimeter divided by 25.14 times 981 times 453.6; or divided by 11,183,000. If English measures are used throughout, the rule becomes: The pull (in pounds) equals the total area of contact (in square inches) multiplied by the square of the number of lines of force per square inch divided by 11,183,000 times 6.45 or divided by 72,134,000.

717. *Give an example of calculating the pull of a magnet.*

Suppose the magnet is made of iron $1\frac{1}{2}$ ins. x $1\frac{1}{4}$ ins., bent into U-shape and magnetized to a saturation of 40,000 lines per square inch. The area of the iron is 1.875 sq. ins. at each end. The pull at each end is

$$\frac{40{,}000 \times 40{,}000 \times 1.875}{72{,}134{,}000} = 41.6 \text{ lbs.}$$

The total pull for both ends will then be twice this, or 83.2 lbs.

718. *Is the above rule for pull of a magnet rigorously correct?*

It supposes that the magnetism is uniformly strong over the whole end of the magnet. If the contact between the magnet end and the piece it is lifting is equally good over the whole surface, the magnetism will usually be equally distributed and the rule in its simple form holds true. If the magnetism is stronger in some places, then the rule becomes more complicated.

719. *How can a magnetic traction table be calculated?*

It is convenient to have corresponding values for lines per square centimeter, lines per square inch, grammes pull per square centimeter, and pounds pull per square inch. Since a square inch equals 6.45 sq. cm., the second column is derived by multiplying figures in the first column by 6.45. Since (see No. 715) the pull in grammes equals the square of the number of lines per square centimeter multiplied by the area in centimeters and divided by 8π times 981, the grammes pull per square centimeter is obtained by squaring the lines per square centimeter and dividing by 24,655, or multiplying by 0.00004056. Since 453.6 grms. equal 1 lb. and 6.45 sq. cm. equal 1 sq. in., the pounds pull per square inch equals the square of the

number of lines per square inch, divided by 8 times 981 times 453.6 times 6.45, or lines per square inch squared divided by 72,134,000 or multiplied by 0,00000001387. Such a table, abridged from Thompson, is given.

MAGNETIC TRACTION TABLE

Lines per Sq. Cm.	Lines per Sq. Inch	Grammes per Sq. Cm.	Pounds per Sq. Inch
1,000	6,450	40.56	.577
2,000	12,900	162.3	2.308
3,000	19,350	365.1	5,190
4,000	25,800	648.9	9.228
5,000	32,250	1,014	14.39
6,000	38,700	1,460	20.75
7,000	45,150	1,987	28.26
8,000	51,600	2,596	36 95
9,000	58,050	3,286	46.72
10,000	64,500	4,056	57.68
11,000	70,950	4,907	69.77
12,000	77,400	5,841	83.07
13,000	83,850	6,855	97.47
14,000	90,300	7,950	113.1
15,000	96,750	9,124	129.7
16,000	103,200	10,390	147.7
17,000	109,650	11,720	166.6
18,000	116,100	13,140	186.8
19,000	122,550	14,630	208.1
20,000	129,000	16,230	230.8

Lines per square inch = 6.45 $\times$ lines per square centimeter.

Grammes per square centimeter $= \dfrac{B^2}{8\pi \times 981} = 0.00004056 \times$ lines per square centimeter squared.

Pounds per square inch $= \dfrac{B^2 \text{ (sq. in.)}}{72,134,000} = 0.00000001387 \times$ lines per square inch squared.

720. *How can a traction curve be made and used?*

A convenient one is made by taking lines of force per square centimeter for ordinates or vertical distances and grammes per square inch of surface for the abscissae or horizontal distances. Using the rule in No. 715, calculate the pull in grammes for a number of values of the lines of force and draw a curve through these points. Then the pull for any other strength of field may be taken from the curve without any calculation. For example, for 10,000 lines of force per square centimeter the pull is found to be 4056 grms.

for each square centimeter of surface of the pole; for 14,000 lines of force the pull is 8000 grms., and so for other points. A similar curve for pounds pull per square inch for various values for the magnetization may be calculated from the rule in No. 716, which may

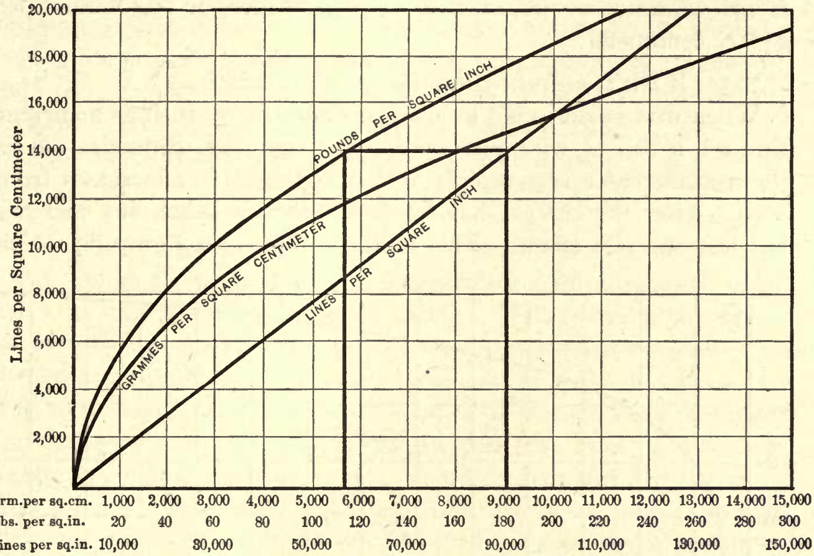


FIG. 720.—MAGNETIC TRACTION CURVES.

be modified to suit. The same curves may be used to show the number of lines per square inch which correspond with any desired number per square centimeter: Since 1 sq. in. equals 6.45 sq. cm., if a line is drawn through the zero and through a point which represents 10,000 lines per square centimeter, and 64,500 lines per square inch, corresponding values may be found for any other value; for example, 14,000 lines per square centimeter equal 90,000 lines per square inch.

721. *How can the pull in pounds be obtained from the curve when the number of lines per square inch is known?*

Suppose there are 90,000 lines per square inch. Follow up the ordinate at 90,000 lines per square inch until it meets the diagonal straight line, which it does at 14,000 lines per square centimeter. Then follow along the horizontal line at the point where the diagonal line was met, until the curve of "pounds per square inch" is met, as at the point indicated by the heavy line upon the curve sheet, and then follow down to the scale for "pounds per square inch," when

it is found that a magnetization of 90,000 lines per square inch gives a pull of 112 lbs. per square inch of surface of the end of the magnet.

722. *How strongly can iron be magnetized?*

There is no definite limit. Cast iron is well saturated at 40,000 lines per square inch, or 6200 per square centimeter. Wrought iron is well saturated at 100,000 lines per square inch, or 15,500 lines per square centimeter.

723. *What is meant by iron being saturated?*

When iron is subjected to a magnetizing force, such as a current through a coil of wire surrounding the iron, the magnetization of the iron increases very rapidly at first as the current increases from zero. After the current has reached a certain value, any increase has less and less effect. This is illustrated in the figure, in which

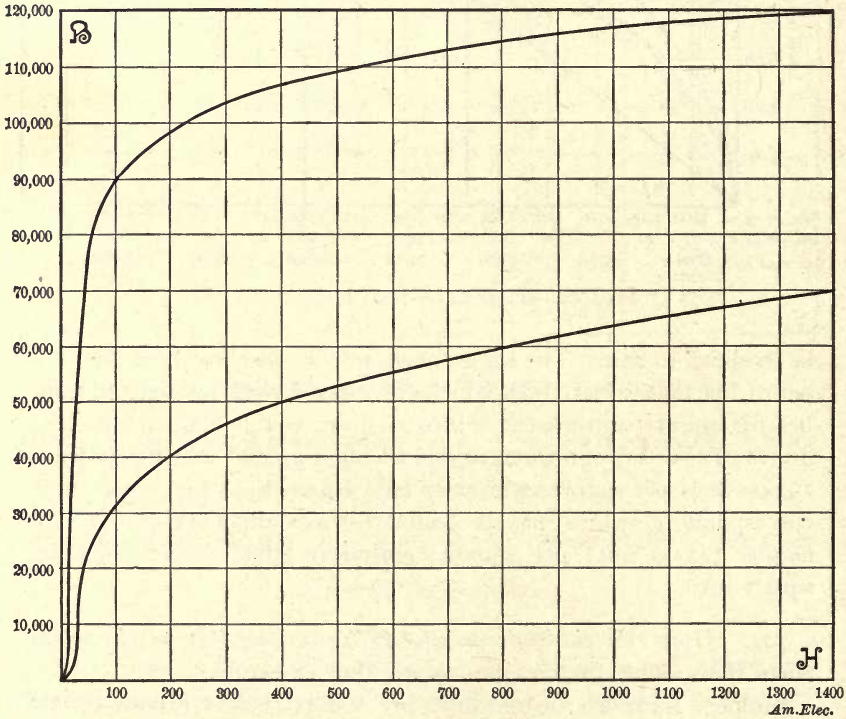


FIG. 723.—MAGNETIC SATURATION CURVES FOR WROUGHT AND CAST IRON.

horizontal distances represent magnetizing force, and vertical distances represent the resulting magnetization of the iron. The turning point in each curve is called the point of saturation, being at about

100,000 for wrought iron and 40,000 for cast iron. These values vary with the composition and hardness of the iron.

724. *What is meant by permeability?*

Permeability is the conductivity for magnetic lines of force. In other words, it is a measure of the ease with which magnetism passes through any substance. The permeability of good soft wrought iron is sometimes 3000 times that of air, varying with the quality of the iron. It also becomes less as the intensity of the magnetism increases. The permeability of cast iron and cast steel is from fifty to 800 times that of air. Some cast steel is nearly as good as wrought iron. (See permeability curves in Fig. 735.)

725. *What is meant by "B" and "H" as applied to magnetism?*

"B" refers to the intensity of magnetization through some magnetic substance, such as iron or nickle. "H" refers to the magnetizing force, or what is equal, the magnetization that would exist if there were no iron present. For example, suppose that a wooden ring were wound with a number of turns of wire and that a certain current were sent through the coil so that fifty lines of force per square centimeter of cross section would be sent through the ring. Now suppose that the ring had been iron instead of wood and that the permeability of the iron were 320, then there would be 320 times 50, or 16,000 lines of force per square centimeter. In this case "H" would equal 50, and "B" would equal 16,000. "H" is also used sometimes to represent loss by magnetic hysteresis (see Nos. 760 to 765), and is commonly used to denote the horizontal component of the earth's magnetism. (See No. 777.)

726. *Is there any definite relation between a current and the magnetization it produces?*

There is a perfectly definite relation similar to that expressed by Ohm's law for electric circuits. The number of magnetic lines of force in any case equals the magnetizing force divided by the magnetic reluctance. Magnetizing force corresponds closely with E.M.F., reluctance corresponds closely with resistance, and magnetization corresponds with current. In this comparison it must be remembered that no energy is required to maintain a magnetic field unless it is doing work, otherwise a permanent magnet would be a source of perpetual motion, which is contrary to reason.

727. *What is the relation of current to magnetomotive force?*

The unit of M.M.F. is the gilbert, and equals that

produced by $\frac{1}{4\pi}$ amp. turn (see Nos. 241 to 250); in other words, 1 amp. turn sets up a M.M.F. of 12.57 gilberts.

728. *How is an electromagnet designed?*

There are a number of methods, all based on the law that the magnetization equals the magnetizing force divided by the reluctance of the magnetic circuit. A common method of procedure is first to decide upon the number of magnetic lines of force that are to be sent through the circuit; then decide upon the intensity of magnetization desired in the iron, thus fixing the area of the iron; the length of the iron circuit is then estimated, allowing what is thought to be enough room for the coils; then calculate the number of ampere turns necessary to produce the desired magnetization; then decide the current to be used, which determines the number of turns of wire necessary in the coils; the size of wire is then determined; this determines the amount of space needed for the coils, and so corrects the length assumed for the magnetic circuit, and allows a still closer approximation to be made upon the number of turns of wire and the exact size of the coil.

729. *What determines the number of lines of force necessary in a given case?*

The purpose for which the magnet is to be used. For a lifting magnet, the rules given in Nos. 715 to 723. For a dynamo or motor, the winding and speed of the armature fix the number of lines of force, while the dimensions of the armature fix the dimensions of the field magnet to some extent. Allowance for leakage must be made, since not all the lines of force are likely to go through the path desired.

730. *What fixes the intensity of magnetization of the iron?*

In some cases the number of lines of force and also the area of the iron are fixed by other conditions, when the intensity equals the total number of lines divided by the area. For example, if 100,000 lines of force are required and the cross section of the magnet is 2 sq. ins., the intensity of magnetization will be 50,000 lines per square inch. When the area is not fixed by other consideration, one would commonly decide to use an intensity of magnetization a little below the "knee" or bend of the magnetization curve, say about 40,000 lines per square inch for cast iron, or about 80,000 to 90,000 for wrought iron or cast steel, since such intensity gives the best economy of iron and copper.

731. *Give an example of calculating a magnet.*

Suppose it is desired to calculate a magnet to lift 500 lbs. Since the pull increases as the square of the magnetization, it is desirable to use a high saturation, say 100,000 lines per square inch. By referring to the table or curve already prepared, it is seen that this

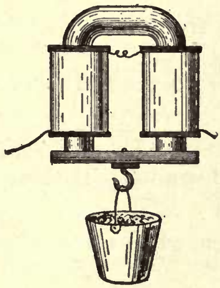


FIG. 731.—LIFTING MAGNET.

would lift 127 lbs. per square inch. Dividing 500 by 127 gives 3.94 as the area of the pulling surface. Since each of the two poles lifts half, the area of each polar surface should be half of 3.94, or a little less than 2 sq. ins. To give a reasonable factor of safety, this should be doubled or quadrupled.

732. *What fixes the length of the iron circuit of a magnet?*

The general shape desired will fix the length approximately. Sufficient space must be allowed for the magnetizing coils, which ordinarily take a space from one to four times the length of the diameter of the iron core.

733. *What determines the number of ampere turns necessary to magnetize a circuit to a desired intensity?*

This is determined by the length and area of the various parts of the circuit and by the permeability of each part, by the general equation:

$$\text{Magnetization} = \frac{\text{Magnetomotive force}}{\text{Reluctance}}.$$

This may be developed in detail as:

$$\phi = \frac{\frac{4\pi NI}{10}}{\frac{l}{A\,u}} = \frac{1.257\ N\ I\ Au}{l},$$

in which ϕ is the number of lines of force, N is the number of turns of wire, I is the current, A is the area of the section of the mag-

netic circuit, l is its length and u its permeability, all in C.G.S. units. This may be put into more convenient form for calculating the number of ampere turns necessary for each part of the circuit as follows:

$$\mathrm{N\ I} = \frac{\phi l}{1.257\ \mathrm{A}u} = .7955\ \mathrm{B}\frac{l}{u}.$$

When all measurements are in inches, this becomes

$$\mathrm{N\ I} = \frac{\phi l''}{\mathrm{A}''u} 0.3132 = 0.31321 \frac{\mathrm{B}''\ l'}{u}.$$

If the magnetic circuit is uniform, the ampere turns may be calculated directly from this formula. If there are a number of unlike parts, the M.M.F. for each part may be calculated by the rule, and the sum of these gives the total number of ampere turns.

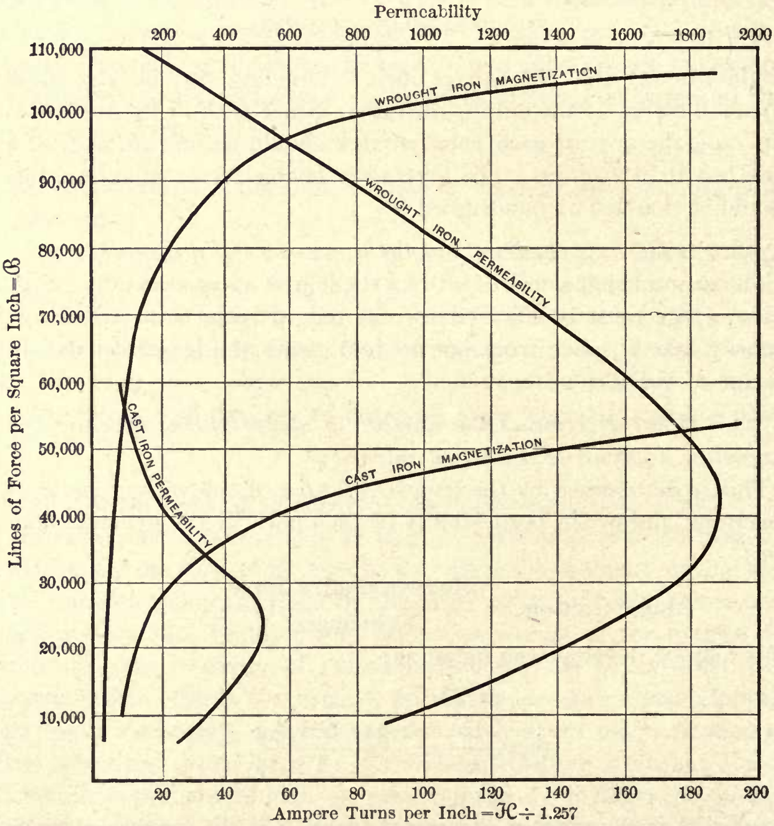


FIG. 735.—CURVES OF PERMEABILITY AND AMPERE TURNS.

734. *Give an example of calculating the number of ampere turns necessary for a magnet.*

Take the case of the lifting magnet discussed in No. 731. Examining the curve or table for good wrought iron, the permeability is found to be about 450 at the assumed saturation of 100,000 lines per square inch. Assume a total length of 15 ins. for the magnetic circuit. Placing the values in the last formula gives

$$N\ I = 0.3132 \frac{100{,}000 \times 15}{450} = 1034$$

for the ampere turns necessary to magnetize the iron. In the case of a field magnet for a dynamo or motor, the calculation would be similar except that it would be more complicated, as there are several parts to be calculated.

735. *Is there a shorter method of calculating ampere turns by means of a curve or table?*

Tables and curves may be made without much difficulty if the permeability curve is known for the iron to be used. The formulæ in No. 733 show that the ampere turns necessary for 1 cm. equal 0.7955 times the number of lines per square centimeter divided by the permeability, and that the ampere turns necessary for 1 in. equal 0.3132 times the number of lines per square inch divided by the permeability. A table may be constructed by taking the permeabilities corresponding to various magnetizations and working out the results

AMPERE TURNS PER INCH LENGTH OF MAGNETIC CIRCUIT.

(*From Poole, Am. El., X:59*)

Lines per Sq Cm.	Lines per Sq. Inch	Cast Iron	Cast Steel	Wrought Iron	Sheet Iron	Air
1,000	6,450	2	..	..	....	2,021
2,000	12,900	4	..	..	....	4,042
3,000	19,350	7	..	..	1.5	6,063
4,000	25,800	12	..	4	2.5	8,084
5,000	32,250	22	..	5	3.2	10,110
6,000	38,700	50	8	6	4.2	12,130
7,000	45,150	85	9	7	5.2	14,150
8,000	51,600	162	10	8	6.4	16,170
9,000	58,050	228	12	10	8.1	18,190
10,000	64,500	306	14	12	10.2	20,210
11,000	70,950	438	17	15	13.5	22,230
12,000	77,400	....	20	19	17.5	24,250
13,000	83,850	....	26	25	24.	26,270
14,000	90,300	....	38	36	32.	28,290
15,000	96,750	....	60	58	50.	30,320

as indicated. The accompanying tables and curves are worked out for excellent grades of wrought and cast iron, and mild cast steel. For close accuracy, curves should be worked out for the particular kind of material used. Since the permeability of air is unity, the number of ampere turns necessary to send the magnetic lines through air equals 0.7955 times the number of lines per square centimeter for each centimeter length of air space, or 0.3132 times the number of lines per square inch for each inch of air space.

736. *What fixes the current to be used in a magnet?*

Sometimes the current is already determined, as in the constant current used for series arc lighting. On telegraph lines the current is fixed within certain limits by the length of the line, the number of offices and the number of cells in the batteries. When the magnetizing coil is to be connected directly across the terminals of a battery or the mains of a constant potential system, such as used for incandescent lighting, the coil must have sufficient resistance to keep the current down to a safe strength. The current through the field magnet coil of a series motor on a constant potential circuit, such as a fan motor or a street railway motor, is governed principally by the work being done by the armature. When the magnet is that of a shunt dynamo or motor (see Nos. 1146 to 1149), the coil should be so calculated that only a small proportion of the total current taken by the machine shall pass through the field magnet coil.

737. *What proportion of the total current is usually taken by the fields of shunt dynamos and motors?*

It varies from 30 per cent or more in small sizes ($\frac{1}{4}$ hp) to 1 per cent in very large machines.

738. *What fixes the size of wire to be used in a magnet coil?*

The size wire is determined both by the allowable resistance and by the current to be carried. As noted in No. 417, magnet coils generally have the wire proportioned for about 850 to 1400 circ. mils per ampere. Another rule is to allow not more than one-third of a watt to be dissipated per square inch of surface of the coil.

739. *How is the winding of a magnet made to have a certain resistance?*

The resistance to be given the coil is determined by the voltage to be applied to its terminals and by the current to flow. By Ohm's law the resistance equals the voltage divided by current. From the size of the iron magnet core, the average length of a turn of wire can be estimated closely; this multiplied by the number of turns,

gives the total length of the wire. The size of wire to give the desired resistance with the calculated length can then be found from a wire table (see No. 348), or it may be calculated from the rule given in No. 352.

740. *How can the permeability of iron be measured?*

There are a number of different methods. The most accurate methods involve the use of ballistic galvanometers, and are reliable only with skilled observers. Comparatively simple methods have been devised by Bidwell, Thompson and others, based upon the attraction between pieces of iron subjected to known magnetomotive forces. Bidwell forms the iron into halves of a ring which has definite dimensions, the two parts fitting closely; a coil of wire is wound around one-half of the ring and the attraction between the two is measured for various values of current, the number of lines of force being calculated from the formula given in Nos. 715 to 717, and the magnetizing force being calculated from the formula given in Nos. 725 and 733. Thompson has arranged a similar device for testing straight rods, called the permeameter.

741. *What is the permeameter?*

It consists of a large block of soft wrought iron in which is a coil of wire. The test piece passes through a brass bushing in one end of the large block and through the coil, its end being carefully surfaced to fit the block. The number of lines of force through the test piece are calculated from the pull required to remove the test piece.

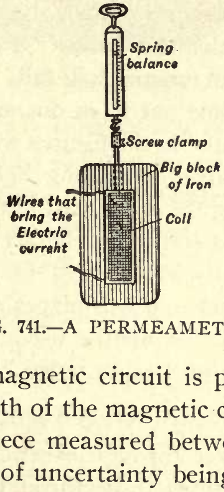


FIG. 741.—A PERMEAMETER.

The reluctance of the magnetic circuit is practically all in the test piece, and the entire length of the magnetic circuit may be considered to be that of the test piece measured between the ends of the gap in the block, an element of uncertainty being the reluctance between the test piece and the upper part of the block. It is not well suited for testing sheet iron.

742. *How many kinds of magnets are there?*

Magnets may be classified according to whether the magnetism is permanent or is temporary, or according to the shape of the circuit.

743. *How are magnets classified according to shape?*

The more common forms are bars, horse shoes, multipolar and

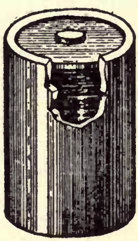


FIG. 743A.—IRONCLAD MAGNET.

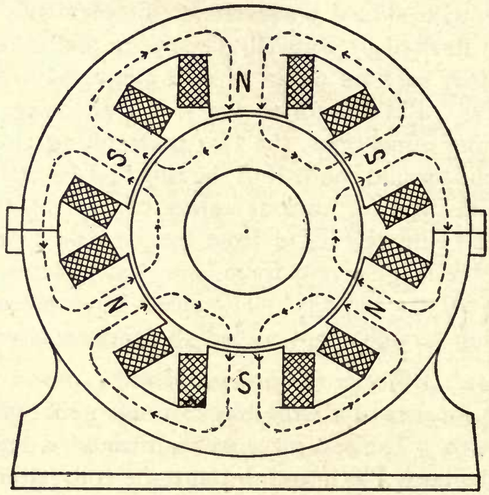


FIG. 743B.—MAGNET CIRCUIT OF MULTIPOLAR DYNAMO.

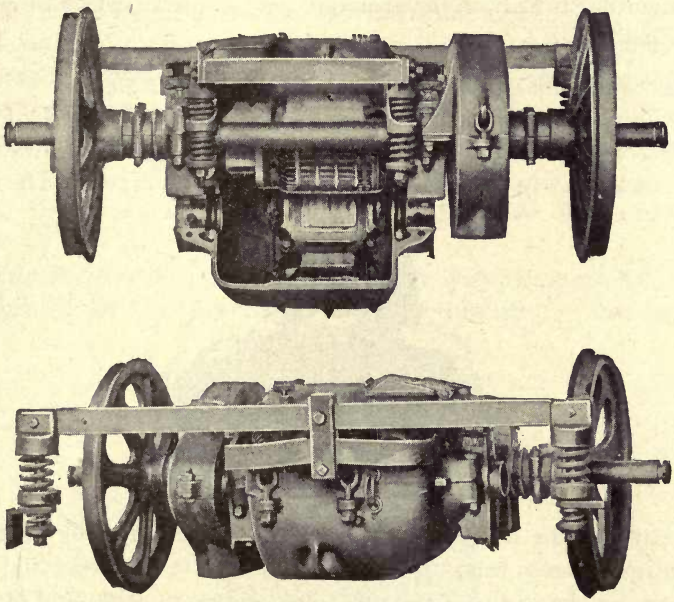
ironclad. Distinctions are also made between those with salient poles and those with consequent poles. It is not always easy to decide in which class a given magnet will fall. A bar magnet is straight and the lines of force come out from one end and pass to the other through the air, as indicated in the figures with Nos. 704 and 708. A horseshoe magnet is shaped something like the letter "U," an example being shown in figure with Nos. 731 and 771. An example of an ironclad magnet is shown in the accompanying figure, 743a. Ironclad field magnets are often used for electric motors for use on street cars and in other exposed places. (Figs. 743c and 743d.) Multipolar magnets are frequently used on large dynamos and motors, multipolar meaning "many poled." (See No. 1121.)

744. *What is the difference between salient and consequent poles?*

All of the lines of force through salient poles come through the same magnetizing coil, while those through consequent poles come partly through one coil and partly through another. It is not always easy to distinguish.

745. *What is meant by magnetic leakage?*

It is found that some of the magnetic lines of force do not remain in the iron, but jump across through the air or other surrounding material for part of the way. This is because air and all other substances have a certain amount of magnetic conductivity, and because iron has at least some reluctance. The magnetic circuit may be compared with an electric circuit immersed in a poorly conducting medium, such as water.



FIGS. 743C AND 743D.—IRON-CLAD MOTORS.

746. *Is there any way to insulate against magnetic leakage?*

Magnetic leakage may be reduced by making the desired path of low reluctance, so that there is little tendency for the lines to seek other paths. No substance has yet been found that will serve as a magnetic insulator. (See also Nos. 747 to 757.)

747. *What is meant by the "stray magnetic field" about a dynamo or motor?*

Hold a screwdriver or wrench near different parts of the iron frame of a dynamo or motor that is running, and it will be attracted more or less strongly at some positions. Wherever the iron is attracted, it indicates that some of the magnetism leaves the field magnet at that point. Some styles of machine have much stronger stray fields than others.

748. *What harm is there in a stray field about a machine?*

It is liable to magnetize watches so that they will not keep correct time; it is liable to attract tools or pieces of iron into the machine, with danger of getting against moving parts or making electrical connections where not wanted; the stray field may cause heating in the pulley. Cases have been known where dynamos magnetized the engine so that the governor would not act properly. Stray magnetism means that part of magnetic field is not useful in generating E.M.F. in the armature, and so means waste of energy in the field coils.

749. *How can magnetism be removed from a watch?*

One way is to place the watch in the center of a coil of wire through which an alternating current is passing. Then draw the watch away slowly while the coil is still carrying current. The magnetic parts of the watch thus have the magnetism rapidly reversed, each magnetization being weaker than the reverse one preceding. The coil may be placed in series with an incandescent lamp and be connected to the electric lighting circuit. If the latter gives continuous instead of alternating current, it may be made alternating by means of a reversing switch or commutator connected around the coil.

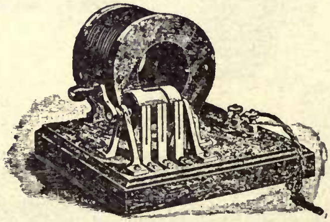


FIG. 749.—WATCH DEMAGNETIZING COIL.

Another way is to hold the watch on a twisted string and bring it near a pole piece of a dynamo; then move it away while it is twisting rapidly.

750. *Is it possible to prevent watches from becoming magnetized?*

Common watches must be kept away from strong magnetic fields or they are liable to become magnetized. Some of the so-called "non-magnetic watches" have the springs and balance wheel made of some non-magnetizable substance, such as palladium, phoshor-bronze or other alloy. Some of these are not affected even by comparatively strong fields.

751. *Do the "magnetic shields" sometimes sold for watches keep out the magnetism?*

They may if made thick enough, but as generally made they are useless except to the seller. No substance has yet been discovered which will not allow magnetic lines to pass through it. Consequently, the only way to prevent magnetism from getting in any space is to keep it away from magnetic fields. One way to do this is to provide an easier path for whatever stray magnetism may be about. The magnetic shields are intended to be made of some metal, such as soft iron or nickel, which is so good a conductor that any magnetic lines of force will pass around through the iron rather than through the space inclosed. A thick iron pocket or case is therefore the best anti-magnetic shield, but it must be thick to be of any value.

752. *Why do many switchboard instruments have cast-iron cases?*

Partly to furnish so good a path for any stray magnetic field from the dynamos or bus-bars that it will pass through the case and not

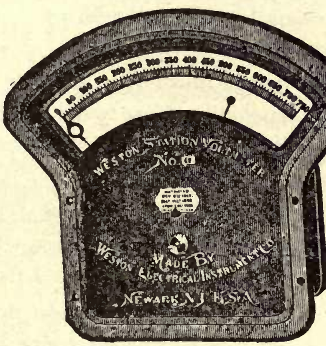


FIG. 752.—IRON-CLAD VOLTMETER.

enter the space inside where it would interfere with the correct working of the instrument.

753. *What is meant by ammeters or voltmeters being "iron-clad?"*

Some instruments have iron cases to make the instrument free from disturbances by outside magnetic fields.

754. *Are ordinary ammeters and voltmeters affected by the stray field about a dynamo or motor?*

Some excellent instruments may be affected so that the measurements are several per cent too high or too low if the instrument is within 10 ft. of an electric machine.

755. *How can one tell whether or not an instrument is affected by a stray field?*

By turning the instrument half-way around, while it carries current, so that the stray magnetism will be relatively in the opposite direction. If it is affected by the field, the instrument will read higher in one position than in the other. The average of two readings, taken in opposite positions, is the correct reading.

756. *Can magnetic leakage from a dynamo or motor be prevented?*

Not entirely. After a machine is finished, it is practically impossible to reduce the magnetic leakage, although it may be made greater by placing iron near the poles. The stray field may sometimes be confined to the space near the dynamo by surrounding the machine by a thick iron case.

757. *Can magnetic leakage be reduced by proper design?*

By making the regular desired path through the armature of very low magnetic reluctance, a larger proportion of the lines from the field will pass through the armature and fewer will stray. The lines follow the easiest path. The armature core should contain plenty of soft iron, and the iron core should come as close to the pole pieces as is possible while allowing sufficient mechanical clearance. Some machines, especially those with toothed armatures, require a wider air space than others, in order to prevent excessive sparking at the brushes.

758. *How can magnetic leakage be detected and measured?*

If a compass needle is brought near a magnet, the needle will begin to vibrate more or less rapidly according to the strength of the magnetic field. The rapidity of the vibration and the amount the needle is turned from pointing north and south is an indication of the strength of the field. Sometimes the strength of the leakage field is indicated by the strength with which the magnet attracts a piece of iron or steel such as a screwdriver or wrench. The number of magnetic lines of force coming out from definite parts may sometimes be measured by the induction through a coil of wire wound around the point to be tested, the induction being measured by a ballistic galvanometer or by a suitable voltmeter when the magnetizing current is cut off or reversed.

759. *What is the difference between a permanent magnet and an electromagnet?*

An electromagnet is one that depends for its power upon the continuous action of an electric current. A permanent magnet is one

that retains the magnetization after the compelling cause has been removed. The softness of the iron and the shape of the magnetic circuit have much to do with the proportion of the original magnetization that is retained. Soft wrought iron retains very little magnetism, especially when the magnetic circuit is partly through air or other non-magnetic material. The harder the iron or steel, the larger proportional part of the maximum magnetization will be retained.

760. *What is meant by hysteresis?*

Hysteresis is a sort of friction between the molecules of iron, or of any other magnetic substance, which causes the magnetization to lag behind the magnetizing current. The result is that when the magnetizing current increases the magnetization of the iron also increases, but when the current decreases the magnetization does not drop off exactly with the current; but for each value of the decreasing current the corresponding magnetization is greater than it was for the same value of the increasing current. This is illustrated in the figure. When the current (or ampere-turns in the coil) increases from zero to a value represented by the length of the base line from *O* to *A,* the magnetization of the iron core increases by an amount represented by the ordinate or vertical distance from *O* to *D.* In the same way, a current *OB* causes a magnetization *OG,* and a current *OC* causes a magnetization *OH.* Now, as the current becomes less, the magnetization corresponding to a given current is the same as before, until the current becomes less than *OB,* and the resulting magnetism is less than

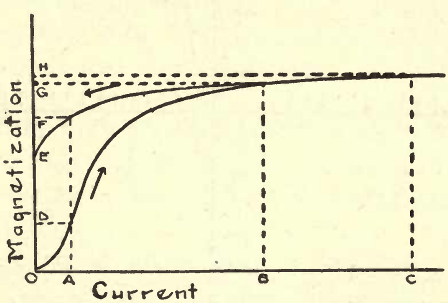


FIG. 760.—MAGNETIZATION CURVES SHOWING HYSTERESIS.

enough to "saturate" the iron. As the current falls below this amount, the magnetism no longer falls off so rapidly as it increased, so that when the current has decreased to *OA,* the magnetism has

only dropped to *OF,* instead of to *OD.* When the current drops to zero, some of the magnetism still remains for a time, and may have the value of *OE* or less. The effect of hysteresis in instruments is that such instruments as depend upon the attraction or repulsion of a soft iron core by a coil do not give the same reading for an increasing current as for a decreasing current, except when the core is magnetically saturated.

761. *What is meant by remanence?*

This is a term sometimes used to denote the amount of magnetism that remains after the current is removed. The amount of magnetism represented by the line *OE* in Fig. 760 is the remanence for the particular case there shown. This is more often called residual magnetism.

762. *What is meant by coercive force?*

Coercive force is the M.M.F. necessary to remove the residual magnetism. This is sometimes called "coercitive force."

763. *What is meant by hysteresis loss?*

When iron is subjected to a magnetizing force that varies through a regular cycle, increasing from zero to a maximum and then decreasing to zero, reversing and increasing to a maximum and decreasing again to zero, the magnetization follows more or less close-

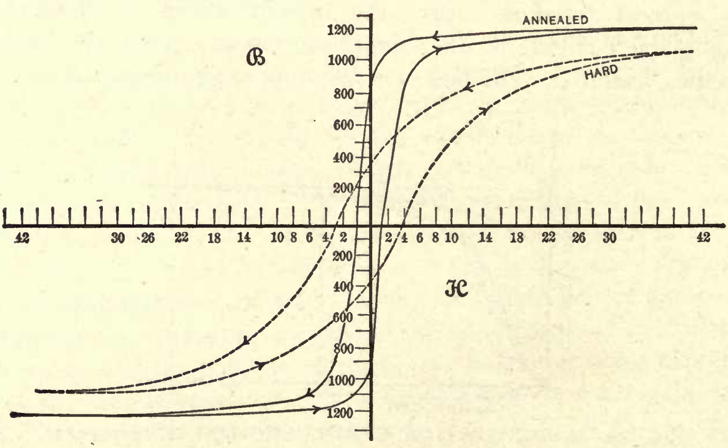


FIG. 763.—HYSTERESIS CURVES FOR IRON WIRE.

ly the changes in the current. In such a case the magnetization curve shown in Fig. 760 becomes doubled, so as to make a sym-

metrical curve. The accompanying figure shows curves for a soft iron wire, the dotted curve showing the hysteresis curve when the iron was hard, and the solid curve showing the magnetization cycle after the same wire was carefully annealed. It requires a certain amount of energy to magnetize and demagnetize iron. If the magnetization followed the same curve in ascending and descending, no energy would be required, since the magnet would restore as much to the circuit in decreasing as it absorbed when increasing. The difference between the two curves represents the amount of loss. This hysteresis loss becomes important in armatures of dynamos and motors and in the iron cores of transformers, since the magnetism passes through many cycles each second, and a large amount of energy may be absorbed in hysteresis.

764. *What becomes of the energy lost by hysteresis?*

It is converted into heat. An armature or transformer whose iron core is hard will heat much faster than one whose iron is carefully annealed, since the area of the hysteresis cycle is larger. The chemical purity of the iron has much also to do with the amount of the hysteresis loss.

765. *How is the hysteresis loss calculated?*

The watts lost per cubic centimeter of iron equal the number of complete cycles of magnetization per second multiplied by the number of lines of force per square centimeter of section raised to the 1.6th power multiplied by a constant and divided by 10,000,000. The constant factor varies from 0.002 for the best wrought iron to 0.016 for good cast iron, and higher figures for hard iron, going as high as 0.075 for very hard steel. For an example, take the case of the armature of a continuous current dynamo. The armature is generally magnetized to about 15,000 lines per square centimeter; this figure raised to the 1.6th power equals 4,806,000. If it is a bipolar machine making 1800 r. p. m., or 30 r. p. s., and if the constant is taken as 0.002, the hysteresis loss per cubic centimeter of the armature core is

$$\frac{0.002 \times 30 \times 4{,}806{,}000}{10{,}000{,}000} = 0.029 \text{ watts.}$$

With alternators the magnetization is likely to be about 7000, and with transformers it is likely to be about 9000, lines per square centimeter. The loss by hysteresis is entirely distinct from the loss that comes from eddy or foucault currents.

766. *Is residual magnetism desirable for any purpose?*

The residual magnetism is the source of power of all permanent magnets. Even in electromagnets, residual magnetism is frequently desirable, as for example in the field magnets of dynamos. The residual magnetism gives an initial field, so that a small E.M.F. is caused when the machine comes up to speed, and this small E.M.F. causes a small current to circulate through the magnet coils so that the machine soon "picks up" if everything is all right.

767. *What determines the amount of residual magnetism that is retained in a magnetic circuit?*

It depends upon the original strength of magnetization, upon the hardness and composition of the iron or steel, upon the shape of the magnetic circuit and upon how nearly it is completely made of magnetic material, and also upon the amount of mechanical shock to which it is subjected. There is a more or less gradual weakening of the residual magnetism, rapid at first and approaching stability as time elapses.

768. *What is meant by "aging" a magnet?*

When magnets are used in instruments, it is quite important that they remain of uniform strength for a long while. For this purpose different methods have been devised for hastening the aging process so that the magnets may soon arrive at the stable part of their life. One method is to subject the magnet to severe mechanical vibration or shock, each treatment removing some of the original magnetization. Another process is to put the magnet in a steam bath. A process used somewhat extensively is to subject the magnet to the influence of a coil carrying an alternating current which is not quite strong enough to reverse the original magnetization. A method sometimes employed is to magnetize the steel and lay it away for a number of years. When a magnet is properly aged it will remain quite constant for a long time, unless it is subjected to abuse. Instruments which contain permanent magnets should therefore be handled carefully, lest the magnets become weakened.

769. *What material is used for permanent magnets?*

Hard steel is most common. Tool steel is good. The varieties known as tungsten steel and chrome steel are excellent for retaining magnetism. After the steel has been forged or otherwise worked up into shape it should be hardened and tempered. The exact temper depends to some extent upon the shape and dimensions of the magnet and upon the particular kind of steel employed. Short magnets should be harder than long ones for the best retentivity.

770. *How are permanent magnets charged?*

The old way was by rubbing them against another permanent magnet or against a lodestone. The modern method is to subject them to the action of an electromagnet. In some cases the coil wire is placed around the hardened steel, in other cases the steel is placed across the poles of a strong electromagnet. It is sometimes desirable to strike the steel gently with a hammer or mallet, so as to set the steel into vibration in order that the molecules may more easily rearrange themselves magnetically. It is also sometimes desirable to place a piece of soft iron across the poles of the magnet and move this up and down or from the bend toward the poles.

771. *What is a compound magnet?*

Magnets are sometimes made up of a number of thin pieces rather than of one thicker piece of steel. The pieces are magnetized separately and then assembled. Compound or laminated magnets are

FIG. 771.—COMPOUND HORSESHOE MAGNET.

generally stronger than those for solid metal, probably for the reason that the thick steel is not hardened uniformly, being much harder on the surface than inside, and, therefore, does not become so uniformly magnetized.

772. *What is a lodestone?*

The lodestone was the first magnet known. It is a piece of magnetic iron ore, sometimes called magnetic oxide, or magnetite, composed of three parts of iron and four parts of oxygen and represented by the chemical formula Fe_3O_4. It was found near Magnesia in Asia Minor, whence came the name magnet. The name Lodestone seems to come from a Saxon word meaning to lead, from the use of the stone as a compass.

773. *How does lodestone become magnetized?*

It is probably by induction from the magnetism of the earth, which in turn is probably caused by electric currents around the earth, due

to some action of the sun. It is known that the earth is a great magnet with one pole near the north end of the earth's axis, and the other pole near the south end of the axis. The magnetic north pole is at about 80 deg. latitude, and about 100 deg. west longitude, being almost directly north from Minneapolis.

774. *Is the earth's magnetism constant?*

It varies slightly each day and also varies from a quarter to a third of one degree at different times during the year. It gradually changes from year to year to a small extent. There are sudden variations of considerable magnitude that are called magnetic storms, which interfere with telegraph and telephone lines, and which seem to have a close connection with the aurora borealis and with sun spots. The apparent position of the north is greatly disturbed by reason of currents of electricity in the earth due to the use of the ground for the return path for electric railways.

775. *What is the compass?*

The compass is a piece of steel magnetized and hung so as to be free to swing on a horizontal or vertical axis. One end of the movable needle will point toward the magnetic north pole of the earth unless disturbed by local influences. The compass is used

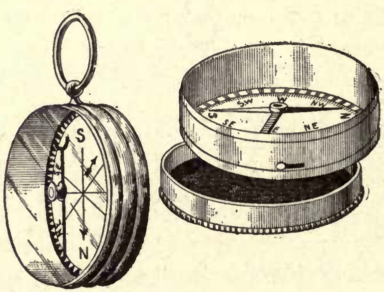


FIG. 775.—MAGNETIC COMPASSES.

largely for guiding navigation, and also land travel in unknown or unsettled regions. The Chinese are said to have been acquainted with the compass since Hoang Ti in 2637 B. C. made an image that always pointed toward the south and guided their armies. The magnetic needle was formerly used, to a large extent, in electrical measuring instruments, but has now been abandoned almost completely on account of the disturbances from the electric railways. The needle is still used to a large extent in land surveying.

776. *What is the inclination compass?*

The inclination compass or dipping needle is so arranged so as to move in a vertical direction. If a magnetic needle were placed directly over one of the magnetic poles of the earth, it would point

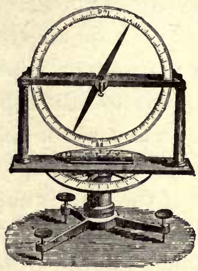


FIG. 776.—INCLINATION COMPASS.

neither north nor south, but directly downward. At the equator it would tend to remain horizontal, and at intermediate points it would tend to take intermediate positions.

777. *What is meant by "H" and "V" in connection with terrestrial magnetism?*

The magnetic attraction of the earth, which is in downward direction somewhere between the vertical and horizontal, may be thought of as made of two elements in the horizontal and vertical directions,

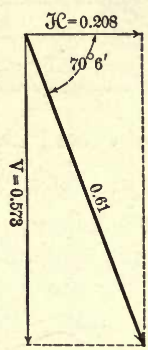


FIG. 777.—COMPONENTS OF EARTH'S MAGNETISM.

and these are called the horizontal and vertical components, which are often abbreviated to "H" and "V." For example, in New York the earth's magnetism has a force of 0.61 dynes in a direction of 70° 6′ below the horizontal. This force may be resolved into two components of 0.573 in the vertical direction and 0.208 in the horizontal, as suggested in the figure.

778. *How does the shape of a magnet affect its permanence?*

If the circuit is completely closed through iron or steel, there is little or no tendency for the magnetism to leave the metal, for the lines of force tend to take the easiest path, which is through iron. But if the circuit consists partly of air, that is, if there is a gap in the circuit, the ends seem to have a depolarizing effect as if one part were magnetized more strongly than other parts, and so reversed their magnetism and used them as return paths. If a complete ring of soft iron is magnetized, almost all of the lines will remain in the iron, and the ring retains its original magnetism after the magnetizing current is removed. But if the ring is cut, so that the lines of force must pass through a small air space, the magnetism quickly disappears when the current stops. If the iron is laminated or slit into small parts near the ends, the magnetism is lost more quickly.

779. *For what purposes are permanent magnets used?*

Permanent magnets are used in the form of needles for pointing to the magnetic north and for locating magnetic masses such as beds of iron ore, or for locating iron masses in places difficult of access; they are used to furnish fields for measuring instruments, for small motors and dynamos, for telephone receivers, for polarized telegraph

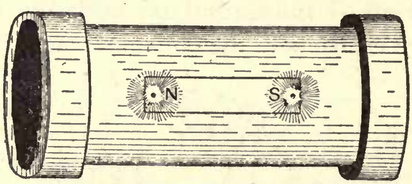


FIG. 780.—MAGNETIZED CASH CARRIER.

instruments, for polarized bells and similar apparatus, for separating magnetic particles from non-magnetic, for attractive toys and quack medical apparatus, for lifting iron, for attracting small particles such as tacks and screws. Some of these uses are also applied to electromagnets and some are really elementary motors, and will be considered in that connection.

780. *How can a magnet be used for locating magnetic masses?*

The principle is illustrated by a simple device sometimes used to locate pneumatic cash carriers which sometimes get stuck in the tubes. Pieces of clock spring are magnetized and riveted to the sides of the leather carriers. By moving a compass along the tube a carrier can be located by the attraction and repulsion of the ends of the compass. An extension of the idea may be used to locate masses of

iron ore by noting the deflections of a compass needle which is moved to different points near the supposed bed of ore.

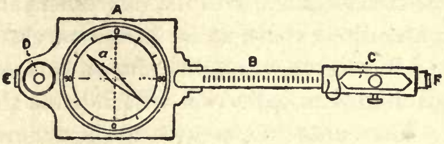


FIG. 781A.—MAGNETOMETER.

781. *How are magnetic surveys made for locating beds of iron ore?*

For locating bodies of magnetic iron ore, sometimes called magnetite or Fe_3O_4, a special kind of compass or magnetometer is used, consisting of an ordinary compass with accurately divided circle and arranged with a controlling magnet sliding on an arm. This may be used as a dipping needle, the magnet on the arm being adjusted so as to balance the horizontal component of the earth's magnetism, when the needle is affected only by the vertical component. When used in the horizontal position, the controlling magnet is removed and the instrument set so that the needle points to zero; the magnet is then replaced and the deflection of the needle is measured, giving an indication of the strength of the horizontal component of the earth's magnetism at that point. To make a magnetic survey by either method, the ground is staked off into squares about 30 feet on

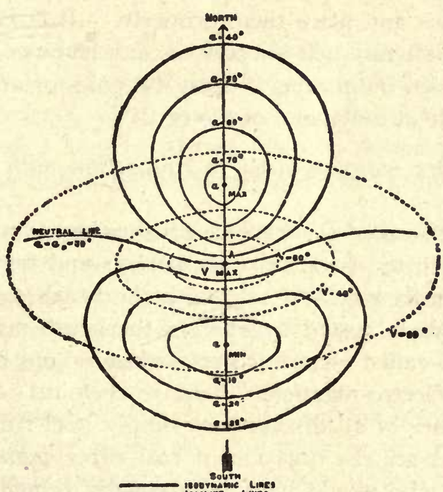


FIG. 781B.—PLAT OF MAGNETIC SURVEY.

a side and a reading is taken at every corner of every square. After the whole district has been tested, a plot of the ground is made on

which the points giving the same deflection are connected by lines which will be found to give closed curves somewhat as shown in the figure; one of the curves taken with the instrument in the horizontal position will be found to extend so far as not to close on itself, and the intersection of this curve with a line drawn between the points of maximum and of minimum deflection will indicate the center of the magnetic mass. The curves taken with the instrument in the horizontal position, measuring the variations in the horizontal component of the earth's magnetism, are shown by the solid lines; those taken by measuring the inclination or the vertical component are shown by the dotted lines which center about the ore mass. These methods are used in Sweden successfully.

782. *How is magnetism applied to hammers and screwdrivers?*

These may be magnetized with one pole near the driving end. It is often very convenient to have a screwdriver magnetized in order to hold a screw on the end and locate it at an awkward place. Much time may be saved in picking up tacks and holding them in place until set by the hammer if the hammer itself is magnetized so that it will

FIG. 782.—MAGNETIC TACK HAMMER.

pick up the tacks and place them properly. It is not necessary to have a special tool for such purpose, as any hammer or screwdriver can be magnetized by putting it upon the poles of an electromagnet or upon one pole of a dynamo or motor.

783. *How are magnets used in connection with quack medical apparatus?*

Some of the so-called electric hair brushes have a magnetized steel wire imbedded in the back and this attracts and repels the ends of the compass needle which is sold with the brush so that "the odic force can always be tested by moving the brush near a compass." Some of the so-called electric corsets, plasters and pads are of the same order. "Electro-magnetic," "electro-chemical" and "magnetic" rings for the cure of all diseases are simply steel rings magnetized. They sometimes are the occasion of real cures caused by the faith of the wearer, who would have been equally benefited by wearing a shark's tooth or rabbit's foot.

784. *For what purposes are electromagnets used?*

The tendency for the magnetic lines of force to become shorter is

used for many purposes, both where simply attraction is desired and where attraction and a resulting motion are desired. The latter is the general case of the electric motor. In some cases the repulsion between similar poles is used either alone or in connection with attraction. In a few cases the tendency for the lines to spread (see Nos. 712, 713) is used alone. The relation between magnetism and induced E.M.F. lies at the bottom of the dynamo, motor, transformer; in short, the most important developments in electrical engineering.

785. *For what purposes is the simple attractive force of the magnet used?*

Magnetic clutches, such as those used for coupling engines and generators in the Arnold system of central power stations, in the regulating device on the new Brush arc dynamos and certain magnetic devices for increasing the traction between moving parts for transportation purposes; lifting magnets, such as used for handling iron and steel plates, for clamps to hold lamps or tools in place on iron surfaces, separating iron particles from turnings or shop sweepings or from the useless rock of iron ores; release magnets, such as used for holding the arms of rheostats in the "on" position; surgical magnets for locating or removing iron particles in the eye or other parts of the body.

786. *For what purposes are magnets used to secure motion as a result of attraction?*

Elementary electric motors, such as electric bells, telegraph instruments, annunciators, electric tuning forks, arc lamp mechanisms, induction coil vibrators, electric organ movements, clocks, electric locks, door-openers, burglar alarms, electric measuring and regulating devices "and other purposes too numerous to mention."

787. *For what purposes is the repellent magnetic action used.*

In connection with the attractive action, it is used in "polarized" apparatus such as the vibrating magneto bell, polarized telegraph instruments, telephone receivers, certain arc lamp regulators, electric motors and measuring instruments.

788. *How can magnetic attraction be used for driving machinery?*

For coupling shafts which are stationary or are running at the same speed, a simple magnetic clutch consists of two cast steel rings carried on steel web plates which are bolted to hubs on the shafts to be coupled. One of the rings, called the field ring, has an annular slot in which the energizing coil is secured; the other, called the armature or keeper, is so mounted as to be separated from the field

ring, when no current passes through the coil, by a narrow airgap. The steel web plates allow the two rings to spring together when current passes through the coil and to spring apart when current

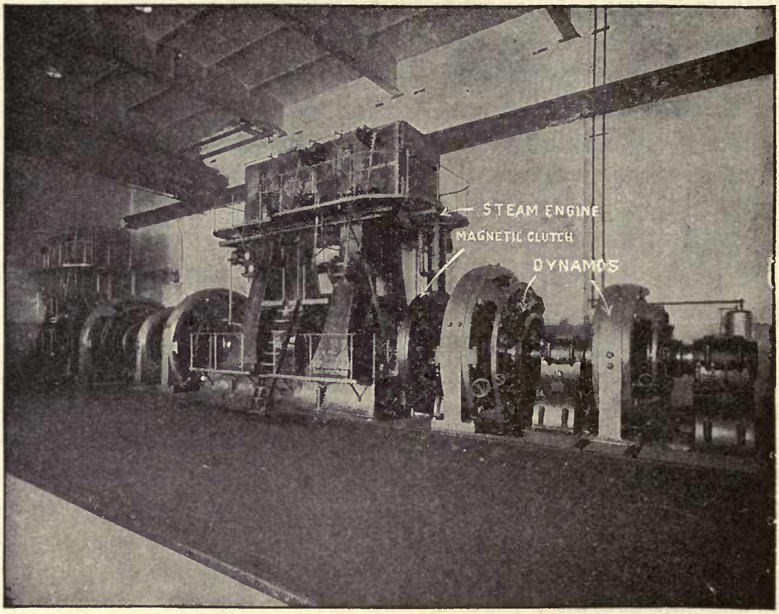


FIG. 788A.—ENGINE DRIVING DYNAMOS BY MAGNETIC CLUTCHES.

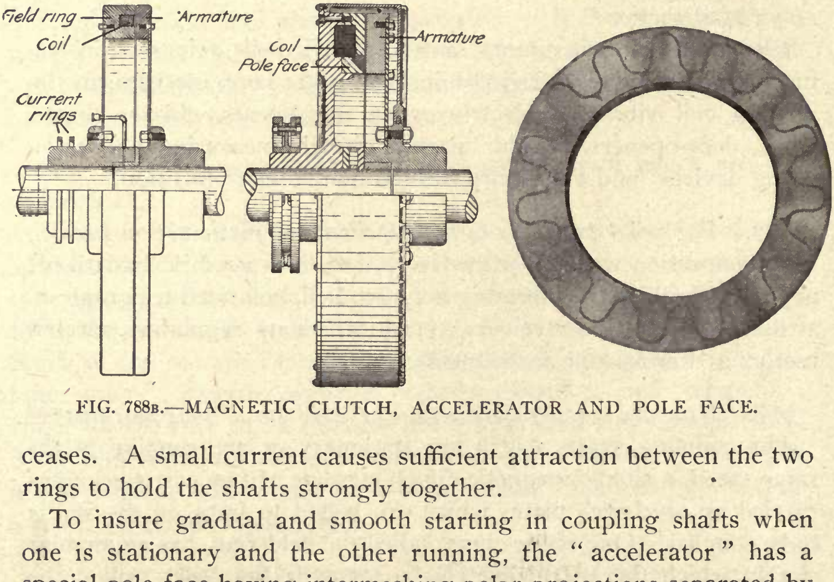


FIG. 788B.—MAGNETIC CLUTCH, ACCELERATOR AND POLE FACE.

ceases. A small current causes sufficient attraction between the two rings to hold the shafts strongly together.

To insure gradual and smooth starting in coupling shafts when one is stationary and the other running, the "accelerator" has a special pole-face having intermeshing polar projections separated by a filling of non-magnetic material such as babbitt metal. When cur-

rent passes through the coil, the magnetic flux through the armature is not uniform as in the simpler clutch, but it circulates in and out from one pole to the next more or less circumferentially instead of all radially; the result is that when the two parts are revolving at different speeds, electromotive forces are induced in the armature (see Nos. 1113 and 1405) which cause eddy currents to flow and exert a torque (see No. 1306) which varies with the strength of the magnetism and the difference in the speeds of the two rings. Either type of magnetic clutch can be operated from any convenient place by simply closing or opening the magnetizing circuit.

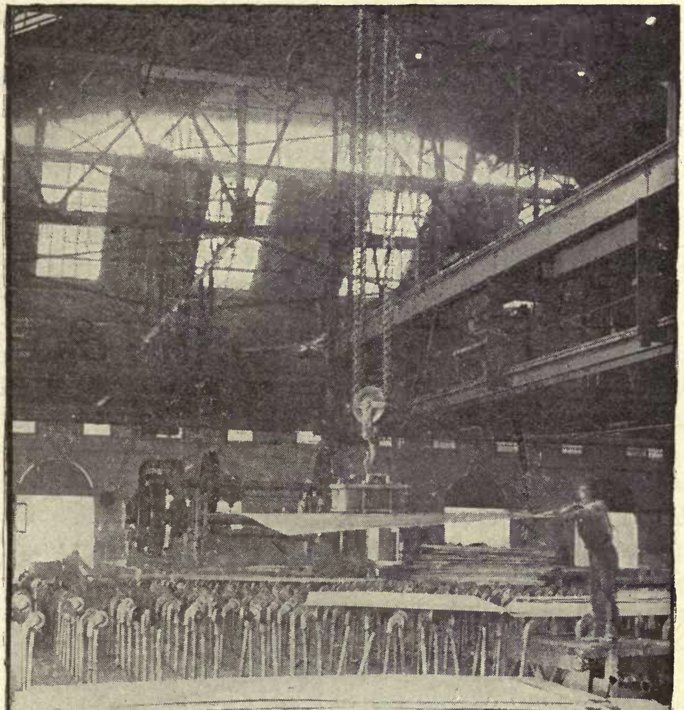


FIG. 789.—ELECTRO MAGNET FOR LIFTING IRON PLATES.

789. *For what are lifting magnets used?*

These are found useful in rolling mills and similar places for handling iron plates, being found cheaper, safer and quicker than the chains and hooks formerly used. Plates weighing as high as 10,000 pounds may be picked up with ease and held while the traveling crane moves them to the place desired. The figure shows their use by the Illinois Steel Company.

790. *What is an eye magnet?*

These are strong, permanent or electromagnets having one pole brought to a point which is very strongly magnetized and which, therefore, will strongly attract any piece of iron or steel near which

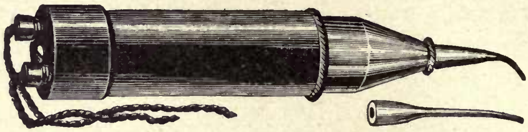


FIG. 790.—EYE MAGNET.

it may be brought. These are useful in removing bits of iron that may become imbedded in the eye or in other places difficult of access. Similar magnets have been successful in withdrawing needles buried in the flesh.

791. *How are magnets used for separating iron from other particles?*

The self-binders for harvesting grain formerly used iron wire for tying the bundles, and since bits of wire would sometimes get mixed with the grain during threshing, the millers found difficulty from the iron getting into their machinery and flour. To obviate this difficulty they placed strong magnets around the hoppers through which the grain passed into the mill and these magnets attracted and held the wires. For separating iron from brass turnings and filings, magnets are arranged around the inside of a thin brass cylinder over which the shop refuse is allowed to fall; the bits of iron are attracted by the magnets and are held by the cylinder until brushed off, while the non-magnetic particles of brass fall at once and so are separated from the iron. This idea has been developed for separating iron ore from the rock in which it usually occurs. Edison has developed this process to a commercial stage.

792. *How does Edison concentrate iron ore magnetically?*

The ore treated is a magnetic oxide of iron held in about three times its weight of easily crushed gangue rock. This is crushed between rollers and then allowed to fall in a thin sheet in front of a series of magnets which deflect the iron particles, but allow the non-magnetic rock to fall vertically. A thin knife-edged partition board separates the two falling streams. The attracted particles are dried and ground and then separated again from the rocky material, then treated chemically and again separated. The magnetic separator at Edison, New Jersey, has a capacity to handle 300 tons of crushed rock per hour.

793. *How are magnetic brakes used?*

Brakes operated by electromagnets are used in connection with

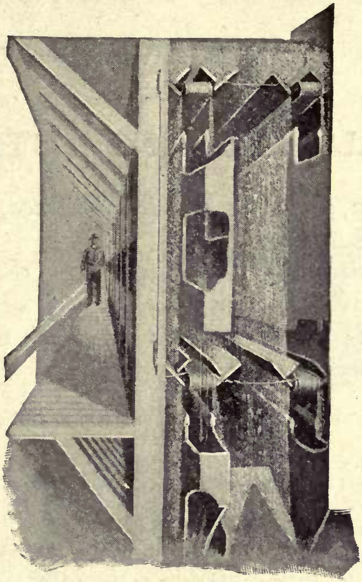


FIG. 792.—MAGNETIC ORE SEPARATOR.

street railway and other motors for stopping the motion. In the case of electric railways the electric brake consists of two discs facing each other much like the Arnold magnetic clutch; one disc revolves with the car axle while the other is stationary; when current is sent through the magnetizing coil, the two are attracted together and the friction quickly stops the car. In some electric elevators and with some motors for mill work where it is necessary to stop fre-

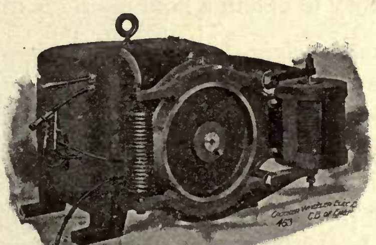


FIG. 793.—ELECTROMAGNETIC BRAKE ON MOTOR.

quently and at a definite point, electromagnets are sometimes arranged to tighten or release a band brake which clamps a pulley on the motor shaft, as indicated in the illustration of an electromagnetic brake on a mill motor.

CHAPTER VII.

ELECTRICAL MEASURING INSTRUMENTS.

800. *Upon what principles are electrical measuring instruments made?*

Every effect of electricity has a quantitative relation to the cause, and nearly every effect has been made the basis of measuring instruments. The effects most commonly used are the static, heating, chemical and magnetic.

801. *How is the electro-static effect used for electrical measurement?*

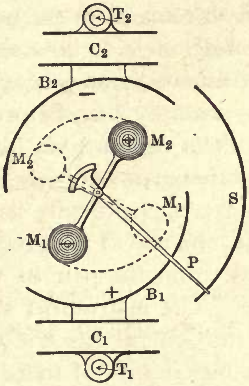
A number of instruments are based upon the fact that two conductors attract one another when any difference of potential or electric pressure exists between them. If one is delicately suspended so as to be free to move, it will approach the other. This is developed in the electro-static voltmeters of Lord Kelvin (Sir William Thomson) and others, also in the electro-static ground detectors of the Stanley and the General Electric companies.

Electro-static voltmeters were considered in Nos. 140 to 147. Current may be measured by fall of potential through a known resistance by means of a static voltmeter, although such instruments are not usually suitable for measuring small voltages. Electro-static instruments have been made for measuring watts, but have not proved sufficiently satisfactory to obtain a hold upon the market.

802. *Describe and explain the electrostatic voltmeter.*

The Kelvin voltmeters suitable for direct or alternating pressures from 40 to 100,000 volts, and the quadrant electrometer suitable for direct pressures as low as 0.001 volt, were discussed in Nos. 142 to 147. The Westinghouse company has developed a line of electrostatic voltmeters for pressures from 2500 to 120,000 volts, using condensers in series. In the figure, M_1 and M_2 are movable condenser elements consisting of hollow spherical end cylinders supported on a steel ball bearing mounted in polished jewels; B_1 and B_2 are curved metallic sheets forming the opposite plates of condensers which M_1 and M_2 approach as they rotate; C_1 and C_2 are pairs of plates of condensers in series, being connected on one side to the instrument

terminals T_1 and T_2 and on their other sides to the inner condenser plates B_1 and B_2. The rotation of M_1 and M_2 is opposed by controlling springs, the position of equilibrium where the attraction



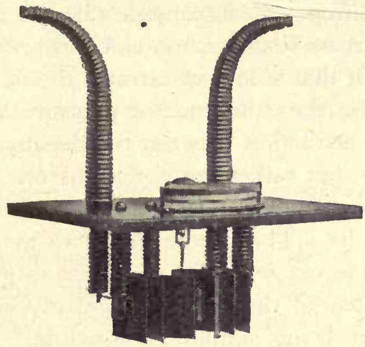


FIG. 802.—WESTINGHOUSE ELECTROSTATIC VOLTMETER.

between the fixed plates B and the moving cylinders M is balanced by the springs being indicated by a pointer P moving along the scale S. The containing case is filled with oil which buoys up the moving element, acts as a damper, maintains insulation and increases the capacity.

803. *Describe and explain the electro-static ground detector.*

One simple form is shown in the figure. It is a sort of differential static voltmeter having one movable vane and two stationary pairs of vanes. The movable vane is electrically connected with the ground;

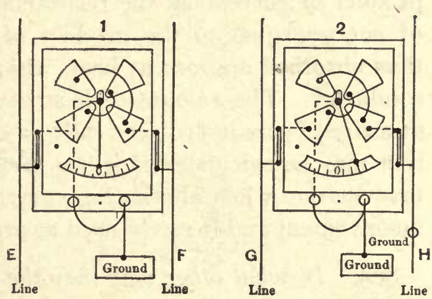



FIG. 803—ELECTROSTATIC GROUND DETECTOR.

one pair is connected to the side of the circuit to be tested and the second pair to the other side. When both sides of the circuit are highly insulated so as to be free from "grounds," the needle is attracted equally by both pairs of vanes and so remains in the neutral position. Now, suppose that the insulation of one side becomes impaired so that it is more or less grounded; the pair of vanes connected with that side now attracts the needle less strongly than before, because the difference of pressure between them is less than before; the attraction between the needle and the other pair of vanes is not less, but rather more, than before, because the opposite wire has approached more nearly the potential of the ground and of the grounded needle. The needle therefore moves away from the pair of vanes connected with the wire that is grounded. The instrument shown is that of the Stanley Company, that of the General Electric Company being similar in principle. For use on circuits of more than 10,000 volts, the stationary vanes are not connected directly with the wires, but are charged inductively by auxiliary vanes which are insulated from the instrument and are connected with the circuit.

In the General Electric static detectors, two adjacent quadrants are connected with the ground, the other two being connected respectively with the two sides of the circuit. The moving vane is charged inductively and is equally attracted by both charged quadrants when the lines are free from grounds, consequently remaining in the zero or neutral position except when a "ground" exists.

804. *How can the heating effect of the current be used for measurement?*

Since every conductor has more or less resistance, it causes a drop in pressure of any current passing, the drop being equal to the product of current by the resistance. This involves the absorption of energy equal to the product of current by drop. The energy thus absorbed appears as heat, which raises the temperature of the conductor. The amount of heat developed in a given time may be measured by an instrument called a calorimeter, from which the current may be calculated if it has been constant. This method was a favorite one when alternating currents first came into use, but it is inconvenient and is rarely used at present. (See Nos. 414 to 421.)

805. *In what other way may the heating effect of the current be used for measuring?*

The energy absorbed by the resistance of the wire raises the temperature of the conductor above that of the surrounding objects. The rate at which heat is interchanged between objects varies directly as

the difference of temperature between them; therefore, heat is given off to surrounding objects more and more rapidly as the temperature of the wire increases. A point will soon be reached where the heat is given off as fast as it is developed in the conductor, and then the temperature becomes constant. At this point the conductor and the surrounding objects have expanded a definite ratio larger than their original size. The expansion of either the conductor or the surrounding objects may be used to indicate the temperature, and therefore indirectly the current which caused it.

806. *How is the expansion of the conductor used to measure current?*

Expansion of a conductor is suitable for measuring direct or alternating current or pressure, since the current through a conductor is proportional to the voltage between its terminals. The

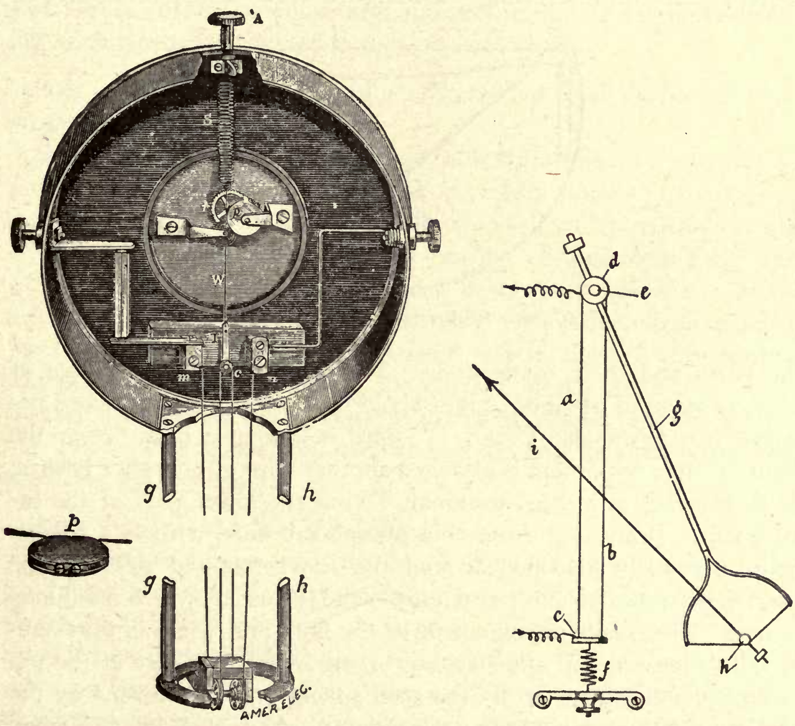


FIG. 806.—CARDEW AND WHITNEY HOT-WIRE VOLTMETERS.

increase in length of the conductor being small, it is multiplied in various ways. In the Cardew voltmeter, formerly the best portable

instrument for measuring alternating E.M.F.s, the expansion of a fine wire running over a series of pulleys was transmitted through a cord to multiplying gearing which moved a pointer across a scale. In a recent Whitney instrument, current passing through a fine wire *a* of high resistance and low temperature coefficient, causes it to heat and lengthen, thus turning the pulley *d* and the attached arm *g*, to whose bifurcated end is attached a silk fiber wound around a shaft *h* which carries a long pointer *i*.

807. *Upon what principles do the Hartman-Braun instruments work?*

These instruments are somewhat similar to those made for some time by Queen & Company. The instruments involve several interesting peculiarities which improve their operation over that of previous types and the method of adapting the hot wire principle to ammeter use is also interesting. The figure shows a general outline of

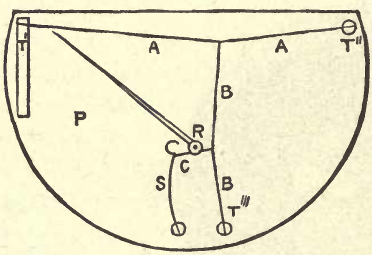


FIG. 807.—HOT-WIRE INSTRUMENT.

the parts and their connections. The hot wire proper, shown at *A A*, is made of platinum silver about 6 or 7 ins. long, stretched between two terminals, T′ and T″, until it is almost taut. Near the center of this wire there is attached another wire of phosphor bronze, *B B*, running to a third terminal, T‴, at the lower part of the instrument. Branching from this phosphor-bronze wire is a cocoon fiber, *C*, which is looped around the jewel-mounted steel spindle carrying the needle, and terminates in the spring, *S*, which maintains it taut. The whole arrangement of the fibre and wires is thus subjected to tension and any slacking or sag of the hot wire at the top is immediately taken up by the steel spring and transmitted by the motion of the cocoon fibre to the pointer. As is well known, when a wire is stretched nearly straight between two points the slightest change of its length causes a great change in the amount of slack. The arrangement of the platinum silver and the phosphor-bronze

wires thus obtains a double multiplication of the deflection in this way, a third multiplication being given by the ratio of the length of the pointer to the diameter of the small spindle on which the cocoon fibre is coiled. Thus a very slight change in length of the wire, *A A*, causes a large movement of the pointer. The whole hot wire movement is mounted on a metal compensation plate made from an alloy whose temperature coefficient is the same as that of the measuring wire. To deflect the pointer of the voltmeter over the full scale a current of .2 amp. is required. For voltmeter work a series resistance or multiplier of constantin is connected in series with the hot wire. For ammeter work the hot wire is tapped at several points by thin silver foil strips which divide it into sections, these sections being placed in parallel with each other. By this means 4 amp. or 5 amp. may be sent through the wire with a drop of potential not exceeding $\frac{1}{4}$ volt (the ammeter hot wire being thicker than the voltmeter hot wire). For higher currents a constantin shunt is used. A magnetic damping arrangment is provided to prevent oscillations.

808. *How is the expansion of objects near a conductor used for measuring the current?*

Several plans have been proposed, although only one seems to be a commercial success. One plan proposed by Forbes is to arrange the conductor as a coil below a small windmill which will be rotated by the air put in circulation by the heating of the conductor. The speed of the windmill, or the number of turns it makes in a given time, registers the amount of the current. Others have tried placing the conductor around a thermometer whose rise of temperature would thus measure indirectly the current in the conductor. One form of this, known as the Wright maximum demand meter, is coming into extensive use for determining the largest current used at any time by a consumer.

809. *Explain the Wright demand meter.*

It consists of a glass tube with two bulbs, around one of which the conductor is wrapped, the tube being partly filled with a liquid, as shown in the accompanying illustrations. The passage of current heats the air in the left bulb and the expansion of the air inside forces more or less of the liquid into the bulb at the right, and into the graduated overflow tube, from which it cannot be removed except by tipping up the meter. The amount of liquid that flows over depends upon the amount of expansion of the air, which depends upon the strength of the current. Any larger current will send more liquid into the overflow or indicating tube, but a smaller current will not.

The instrument thus indicates the largest amount of current used at any time, which gives the station manager a basis for estimating the

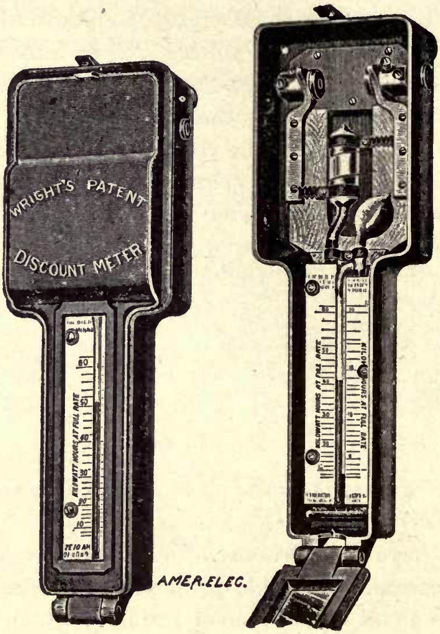


FIG. 809.—MAXIMUM DEMAND METER.

discount to be allowed from the bill as calculated from the regular meter.

810. *Is any other heating effect used for measuring the current?* The fact that the resistance of a conductor changes with the temperature has been used for purposes of measurement, notably in the Howell lamp indicator or voltmeter, formerly made by the Edison Company.

811. *Has the change of resistance with temperature been applied to measuring instruments?*

This effect has been used in the Howell instruments for measuring voltage, and in a number of instruments for measuring temperature such as electrical thermometers, and in instruments for measuring radiant heat such as the bolometer.

812. *What is the principle of an electric thermometer?*

A conductor having a high melting temperature, such as carbon or platinum, is inclosed in some refractory substance such as por-

celain and exposed to the high temperature which is to be measured. Knowing the temperature coefficient of the conductor and the change in its resistance, the temperature may be calculated. Such an instrument is often called a pyrometer. For use at high temperatures, carbon must be sealed away from air to prevent its combustion. For measuring very small differences of temperature, the bolometer has been found wonderfully sensitive.

813. *What is the bolometer?*

The common form of bolometer consists of two similar circuits containing conductors of a material whose resistance changes rapidly with changes of temperature; these are arranged so that one may be exposed to the source of heat under investigation, while the other is protected from it. The two circuits are connected respectively to the two coils of a differential galvanometer which are wound or connected oppositely so that the needle is only affected by the difference between the currents in the two coils. When both circuits are connected to the same battery and both are at the same temperature, equal currents flow through the two coils and the needle is not affected; but if the temperature of one is different from that of the other, their resistances vary and the currents no longer balance, thus causing a deflection of the needle. Such instruments have been made so sensitive as to be affected by the heat from a candle a mile distant and even to show the heat from the distant stars.

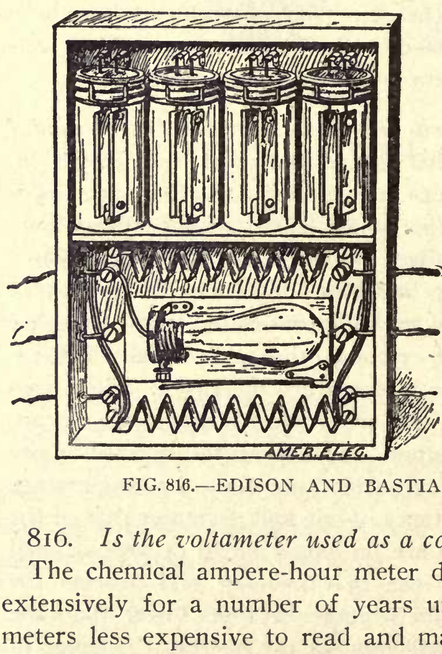
814. *Upon what principle was the Howell lamp indicator made?*

It depended upon the fact that the resistance of most metals increases with rise of temperature, while that of carbon decreases. Two circuits are arranged so that when equal or proportional currents flow in each, one neutralizes the effect of the other upon a galvanometer or other current indicator. One circuit contains a carbon resistance consisting of a special incandescent lamp; the other contains a long fine wire of iron or some other such metal whose resistance increases rapidly as its temperature increases. These two circuits are coupled in multiple and are connected across the circuit, whose voltage is to be kept constant. If the pressure increases, more current flows through each circuit and thus raises the temperature of each; this increases the resistance of one and decreases that of the other, so that the two currents are no longer equal or proportional as before, so that one affects the galvanometer and deflects the pointer in one direction. If the voltage becomes lower than the standard for which the instrument was set, the resistances change in the opposite direction and the pointer is moved accordingly. This

instrument does not measure the voltage, but simply shows whether it is above or below the standard. It is not made now.

815. *What is the electro-chemical effect as used for measuring current?*

When current passes through any liquid conductor (unless it be an elementary substance, such as mercury) the liquid is decomposed, part going to the "anode," the conductor where the current enters the liquid, and part going to the "cathode," where the current leaves the liquid. The anode is dissolved to some extent. When used for measuring, it is customary to have as the liquid a solution of some salt of the same metal that is used for the anode. (See Nos. 644 to 652.) In the standard form, pure silver is used for the anode, a solution of nitrate of silver for the electrolyte (the liquid), and a platinum bowl for the cathode. A current of 1 amp. deposits 0.001118 grm. of silver per second upon the cathode. Such an apparatus is called a voltameter.



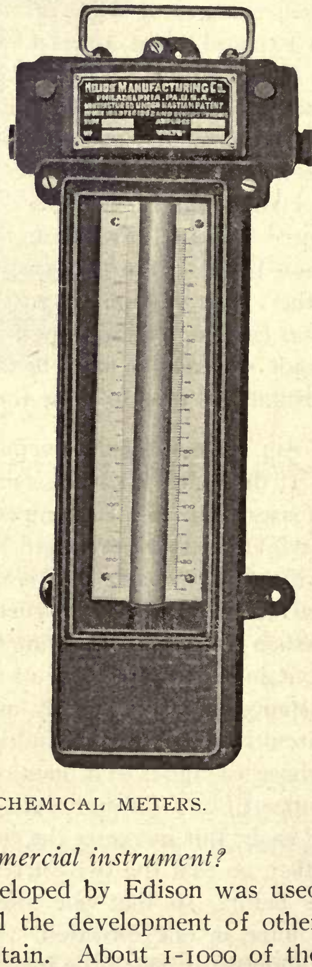


FIG. 816.—EDISON AND BASTIAN CHEMICAL METERS.

816. *Is the voltameter used as a commercial instrument?*

The chemical ampere-hour meter developed by Edison was used extensively for a number of years until the development of other meters less expensive to read and maintain. About 1-1000 of the whole current passed through the voltameters consisting of two zinc plates in a zinc sulphate solution, the two bottles being in series (as

a check) and connected around a German silver "shunt" which took the main current; the weight lost by anodes measured ampere-hours. The cut shows a meter for ampere-hours on each side of a three-wire system. An incandescent lamp operated by a thermostatic switch (on the same principle as recent blinking sign lights), became lighted whenever the temperature became low enough to endanger freezing.

The more recent Bastian meter sends the entire current through nickel electrodes in an alkaline solution, the ampere-hours (or the watt-hours when multiplied by the average voltage) being indicated by the difference in the level of the liquid which is decomposed into gases which escape.

817. *Is the voltameter an accurate instrument?*

It is in the hands of skilled operators. In fact, the voltameter has been adopted by the British and by the United States governments as the standard means for calibrating instruments for measuring currents, but is almost never used. (See No. 227.)

818. *Does the chemical meter measure the watt-hours used by a consumer?*

It measures ampere-hours, which may be multiplied by the average voltage so as to indicate watt-hours. The meter is commonly calibrated to show kilowatt-hours.

819. *Can the voltameter be used as a voltmeter for measuring pressure?*

Not in its ordinary form. It has been proposed to make one with a very high resistance, in which case the current would be proportional to the pressure. The change of weight of the electrodes might then be taken to determine the average pressure. This has not been very successful.

820. *Can the voltameter be used as an ammeter?*

Not directly. The change of weight during a given time measures the average current during that time, so that it may be considered as an ammeter when the current remains constant. It is not convenient for such purposes and is only used for scientific tests.

821. *Is the voltameter suitable for use as a meter for alternating currents?*

No. Since the alternating current goes first in one direction and then in the other, whatever effect might be produced by one alternation would be reversed by the next, except that in voltameters in which gases are produced, some of the gas might escape between reversals.

822. *How is the magnetic effect of the current used in electrical measurement?*

Some instruments are based upon the mutual attraction or repulsion between wires carrying current due to the magnetic field of force surrounding the wires; some use the reaction between the magnetic field about the wire and an independent field due to some other source; some depend upon the attraction between the wire and the field induced by it in a soft iron core.

823. *Is it necessary to have iron in a magnetic circuit?*

Not always. In some cases it is better to have none, as in the case of certain instruments for measuring alternating currents, such as the Siemens electrodynamometer, the Weston alternating-current voltmeter or the Thomson recording wattmeter.

824. *What is there in common between measuring instruments and electric motors?*

Nearly every instrument for measuring current, pressure or energy is really a motor in which the armature can rotate through only part of a revolution. A brief discussion of certain instruments may therefore properly introduce the study of the motor.

825. *What is the electrodynamometer?*

It is an instrument for measuring amperes, volts or watts. The Siemens electrodynamometer consists of two coils at right angles to each other, one coil being stationary while the other is free to rotate. The figure shows a common form, in which the stationary coil is inside, the movable coil being in the form of a rectangle outside

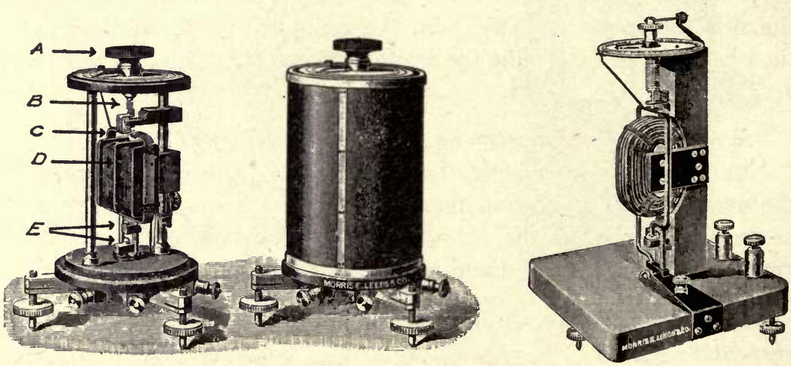


FIG. 825.—ELECTRODYNAMOMETERS.

A = Turning knob B = Spring C = Moving coil
D = Stationary coil E = Mercury cups

the other and hung from a thread inside the spiral spring. Electrical connection with the movable coil is made through mercury cups into

which the ends of the coil dip. When currents are sent through the two coils the magnetic stresses tend to move the two coils so as to become parallel, and the movable coil then begins to rotate to a position at right angles to that shown in the figure. The movable coil is then brought back to its original position by rotating the torsion head to which one end of the spring is attached. The amount of twist given the spring by the torsion head in order to bring the coil back to zero is a measure of the current in the two coils.

826. *How can the electrodynamometer be used as a voltmeter?*

By having both coils made of a large number of turns of fine wire the instrument is sensitive to small currents. Then by connecting a high resistance in series with the instrument it may be connected across the terminals of the circuit whose pressure is to be measured. The electrodynamometer really measures the current passing through it, but by Ohm's law this is proportional to the pressure or E.M.F. at its terminals, and the force is therefore a measure of the E.M.F.

827. *How can the electrodynamometer be used for measuring watts?*

The magnetic force of each coil is proportional to the current through it, and the force tending to rotate the movable coil equals the product of the magnetic forces of the two coils. If, therefore, one coil is suitable for carrying the main current, and the other consists of many turns of fine wire with high resistance suitable for connecting across the circuit, the force between the two coils will be proportional to the product of current by volts, and therefore measures the watts. The instrument is then called a watt-meter.

828. *What are the advantages of the electrodynamometer?*

It is suitable for measuring currents either direct or alternating, and its calibration is independent of the frequency or form of the alternating current. Having no iron or permanent magnets, its reliability and permanency depend upon the spring, which experience shows does not change from year to year.

829. *What are its disadvantages?*

The instrument must be kept carefully leveled, and must be kept free from outside magnetic influences. It is not direct reading, but the torsion head must be adjusted so that the pointer comes back to zero each time before a reading can be made. It therefore requires some time and careful handling, and is of little use when the current fluctuates rapidly.

830. *Are there other instruments based on the electrodynamic effect of the current?*

Besides the Siemens electrodynamometer, there are other forms by Kohlrausch, Weber, Thomson and others, which are also zero instruments that must be adjusted for each reading. Some others, such as the Weston alternating-current voltmeter, are direct reading, the coils being so shaped that the movable coil can rotate through a wide angle while a pointer attached to it travels across a scale and shows the voltage or E.M.F. at the terminals of the instrument. In the Bristol recording voltmeter the two coils are parallel and repel one another, the movable coil carrying a pointer that moves across a scale.

831. *How can one tell whether a wire will be attracted or repelled in a given case?*

The general rule is that (a) the lines of force are considered as coming from the north pole and going into the south pole (b), the lines of force around the current are in the direction of motion of the hands of a clock when one looks in the direction in which the current is considered as flowing, (c) the effect of bringing two magnetic forces together is to strengthen the field where the two forces are in the same direction and to weaken it where they are in opposite directions, and (d) the lines tend to separate so as to make the field of uniform strength. It is easier for some to remember the "rule of thumb" for the motor or dynamo.

832. *What is a rule of thumb for remembering the direction of pull on a wire?*

It is similar to that for the E.M.F. of a dynamo, except that the left hand is taken instead of the right hand. Spread out the thumb and

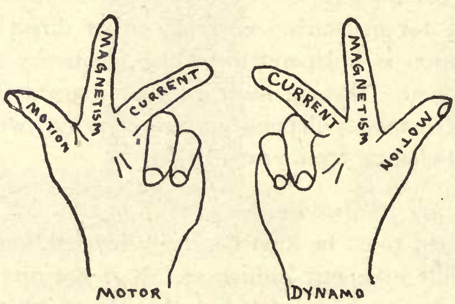


FIG. 832.—MNEMONIC RULE.

first and second fingers, so that all stand at right angles to one another. Let the forefinger represent the direction of the lines of force, the center finger the direction of the current, and the thumb the

direction of the motion. Then, if one knows any two, he can easily get the direction of the other. The fingers of the right hand may be remembered as for the dynamo and the left for the motor, since the right hand usually comes before the left and the dynamo must work before the motor will start. The figure shows it all.

833. *What instruments are developed from the force between a current and a magnetic field?*

The large class of instruments using permanent magnets, also many using electromagnets. Many of these are simply portable forms of d'Arsonval galvanometers.

834. *What is the d'Arsonval galvanometer?*

It consists of a coil suspended between the poles of a magnet so that it may rotate through a small angle when current passes. The figures show a simple form arranged for fastening to a wall and a more sensitive one for fine work. The coil is suspended by a small flat wire which forms one terminal of the coil, the connection with the other terminal being made through a very weak spiral spring below. The coil carries a pointer that moves across the scale for

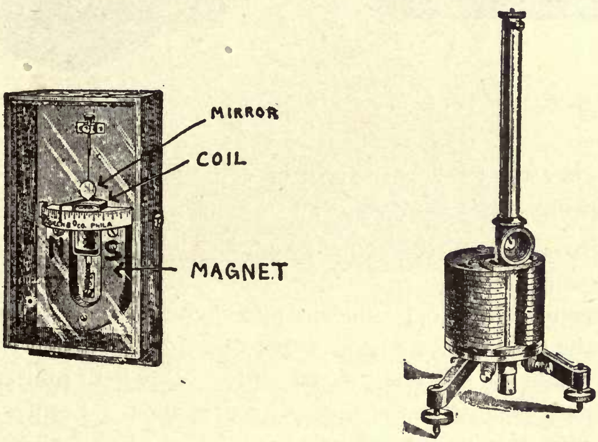


FIG. 834.—D'ARSONVAL GALVANOMETERS.

reading large deflections. A mirror also fastened to the coil allows the use of a telescope and scale for reading very small deflections of the coil caused by correspondingly small currents. The cylindrical piece of iron in the center of the coil in the simpler instrument is stationary, and simply serves to better the magnetic circuit, and so make the field stronger than it would be if the whole space between the poles consisted of non-magnetic material, such as air.

835. *What instruments are developments of the d'Arsonval galvanometer?*

Those best known are the Weston ammeters and voltmeters, in which the moving coil is supported between jeweled bearings, the current being taken into and out of the coil by means of delicate hair springs, which also serve as controlling springs to balance the deflecting force of the current in the coil. The "heart" of the instrument is shown in Fig. 835A, in which parts of the magnet and pole

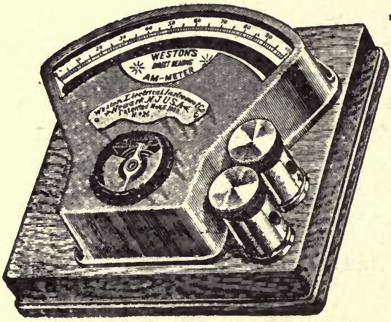


FIG. 835.—AMMETER.

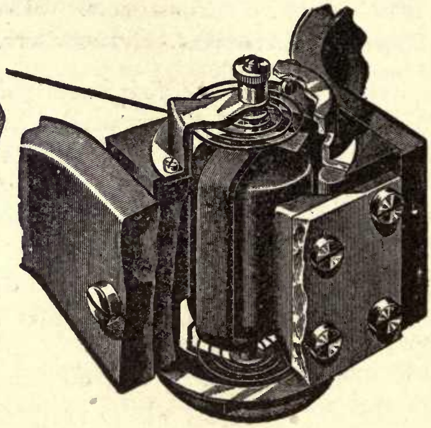


FIG. 835A.—WORKING PARTS OF WESTON INSTRUMENT.

piece are cut away to show the moving coil, the central soft iron core, the two springs and the pivots.

836. *Do not the currents in the two sides of the coil go in opposite directions and so oppose each other?*

The currents are in opposite directions, going up on one side and down on the other. The result is that one side is pulled toward the observer, while the other is pushed away. But both pull and push tend to rotate the coil in the same direction about its center, and so work together to give the deflection.

837. *What is the general principle upon which electromagnetic instruments are based?*

Electromagnetic instruments, which include nearly all ammeters and voltmeters, depend upon the fact that every current is surrounded by a magnetic field which reacts against any other magnetic force in the same field. This is illustrated by Fig. 1, which shows the effect of a wire carrying a current through the field of a magnet. The lines of force, which formerly went from one pole to the other by

straight lines or short curved ones, as shown in Fig. 2, now are stretched by the effect of the current, and the wire must move in toward the magnet poles in order to relieve the tension. In the figure

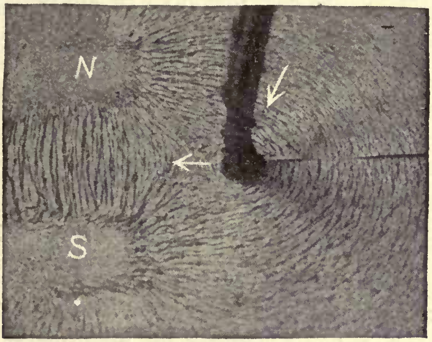


FIG. 837-1.—EFFECT OF CURRENT IN MAGNET FIELD.

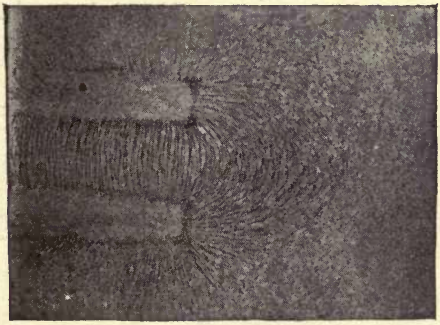


FIG. 837-2.—FIELD BETWEEN POLES OF MAGNET.

the current is shown as going from or into the paper; if the direction of the current had been opposite, the current would have been repelled, since the lines of force would then have been crowded together closer on the inside toward the magnet.

838. *Does the whole current pass through the coil in an ammeter of the d'Arsonval type?*

Only in those for very small currents. In order to be sensitive, the hair springs must be small and not be allowed to carry much current, or they may get hot enough to lose their temper. A voltmeter takes so little current that the whole of it can safely pass through the delicate hair springs without danger, but only a small fraction of the current through an ammeter can pass through the springs.

839. *How can the ammeter be made to measure correctly when only part of the current goes through the coil?*

The coil is arranged so that a definite proportion of the whole current passes through it. A large conductor of low resistance is connected directly between the two terminals or binding posts of the instrument; the coil is connected as a shunt around a definite part of this main conductor; then, since the two are connected in multiple and each branch has a definite resistance, the current divides between the two branches directly in proportion to their relative conductivities, or inversely according to their resistances. The coil, therefore, takes a definite part of the whole current, and the force moving it and its pointer away from the zero position is directly proportional to the whole current.

840. *Upon what basis are switchboard ammeters constructed, in which the instrument is connected by small wires like lampcord?*

In these instruments, which are now made by several companies, a "shunt" is connected directly into the bus-bars, while the galvanometer part may be placed wherever desired.

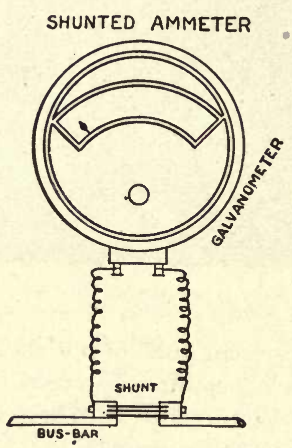


FIG. 840.—SWITCHBOARD AMMETER.

The part usually thought of as the instrument is really a d'Arsonval galvanometer, practically the same thing as the voltmeter, and contains a permanent magnet with a coil mounted on pivot bearings and controlled by hair springs, which also carry the current into the coil. The coil with its hair springs and the connecting cords have a definite resistance; when these are carefully connected to the "shunt" in the bus-bars, a small, but definite portion of the whole

current goes through the cords and the galvanometer, which thus measures the whole current. Some instruments have several shunts for different ranges.

841. *What advantage is there in this kind of instrument?*

It saves considerable expense in building the switchboard, since the bus-bars do not have to be carried to any particular place to suit the instrument. Also, if desired, a number of galvanometers may be connected around the shunt, so that the current may be read from different points. It is also possible to do away with the regular shunt entirely and connect the galvanometer cords to points on the bus-bars themselves (which points must be found with care), and so do away with the two joints in the bus-bars otherwise necessary. It is also possible to use the same galvanometer for measuring the currents in several different circuits.

842. *How can one instrument be used to measure currents in different circuits?*

By having a double pole switch with several sets of terminals, like a voltmeter switch, the galvanometer may be connected around definite points on several circuits. It is necessary that the switch be

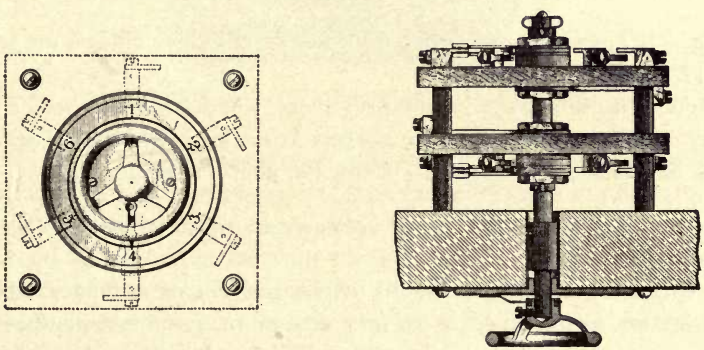


FIG. 842.—MULTIPLE POINT INSTRUMENT SWITCH.

made with great care, so as to have negligible resistance and so as to make sure and uniformly good contacts. If desired, the same galvanometer may be arranged so as to have a variety of ranges.

843. *How can the range of current measured by a galvanometer be varied?*

The range of the galvanometer may be varied by simply changing the ratio of the resistance of the coil with its connections, as compared with that of the "shunt." A given deflection or motion of the coil in the galvanometer is always caused by the same current; but

that current may be any desired fraction of the whole current in the main circuit, since the whole current divides itself between the "shunt" and the galvanometer circuit in inverse proportion to their relative resistances. If the resistance of either circuit is changed while that of the other remains constant, the ratio of the currents changes accordingly. Usually it is not desirable to change the resistance of the galvanometer circuit; the only alternative is to change that of the shunt. For a simple example, suppose that when the galvanometer is shunted around 1 ft. length of a bus-bar or other conductor, 80 amps. give a full scale deflection of the galvanometer needle; if the same galvanometer is shunted around 10 ft. of the same conductor, the relative resistances have changed so that the same current, as before, is sent through the galvanometer when the whole current is a trifle more than 8 amps. In the same way, if the galvanometer is shunted around 100 ft. of the conductor, the galvanometer will give a full scale deflection when the whole current is a little more than 0.8 amp. The simplest way of finding the exact length of conductor to take as a shunt for a given range of current is to "cut and try," although the method of calculating it mathematically is not very difficult.

844. *What is the difference between an ammeter and an amperemeter?*

There is no difference; some prefer one word and some prefer the other. Ampere-meter is more correct from an etymological standpoint, but most people seem to prefer the abbreviated form.

845. *What is the difference between an ammeter and a current indicator?*

A current indicator is usually a cheap form of ammeter whose readings are not claimed to be very accurate. For most plants it is not necessary to know the current exactly and a cheap ammeter is good enough. The voltage is the factor of importance, and it is better to put more money into a good voltmeter and less into the ammeter.

846. *Is there any difference between a voltmeter and a voltameter?*

Yes; there is a wide difference. A voltmeter is an instrument similar to an ammeter, except that it is arranged to measure voltage or pressure. The voltameter, on the other hand, is an instrument based upon the chemical effects of the current and measures the product of current by time. The Edison chemical meter is an ex-

ample of a voltameter used to determine the ampere-hours of current used by a consumer. (See Nos. 815 to 821.)

847. *What is the arrangement of voltmeters that have different scales corresponding to different binding posts?*

Such instruments usually have only one galvanometer coil, but have a number of different resistances in series. One terminal connects directly with the galvanometer coil; the terminal for the lowest scale is connected directly to the other terminal of the coil, or often to a small adjusted resistance coil in series with the coil; the next higher terminal connects with the circuit after it has passed through

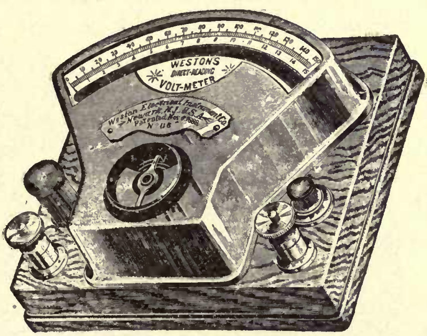


FIG. 847.—DOUBLE-SCALE VOLTMETER.

a second and higher resistance. The theory of the instrument is as indicated in Nos. 848 and 931. A certain current is required to move the pointer to a certain mark; but the pressure or voltage necessary to send such current through the instrument depends upon the resistance of the circuit; hence each terminal governing the resistance in series with the galvanometer coil determines which scale shall be read for the true voltage. For "multipliers" see No. 931.

848. *What is the difference between a voltmeter and an ammeter?*

An ammeter measures current, while a voltmeter measures pressure (or E.M.F.). As actually constructed, most voltmeters are simply special forms of ammeters. From Ohm's law, the current through a given circuit equals the pressure at its terminals divided by its resistance; if a high resistance is connected in series with a sensitive ammeter that will measure very small currents, then the current passing through the circuit is directly proportional to the pressure or voltage at its terminals, and the instrument may be calibrated to read volts.

849. *What is meant by calibrating an instrument?*

Calibration refers to the construction of the scale of the instrument, or to the determination of the value of different positions on the scale. For example, suppose that an instrument has a resistance of 10,000 ohms and that 0.001 amp. (or 1 milliampere) causes the pointer to move to a point, say, 1 in. from the zero or starting point. The pressure necessary to send 0.001 amp. through 10,000 ohms is 10 volts, since $E = C \times R$. That point on the scale might be marked either as 0.001 amp. or as 10 volts. In a similar way, the value of every other point on the scale might be determined. If the current values are marked on the scale, we say that the instrument is calibrated to read amperes or milliamperes; while if the scale were marked to show the pressure at the terminals of the instrument necessary to give the same readings, we would say that it was calibrated to read volts. (See No. 924.)

850. *Why does a voltmeter have a high resistance?*

For the sake both of economy and of accuracy. By making the galvanometer very sensitive, less current is required to operate it, and, as a result, more resistance is needed to keep the current down to that required. Some voltmeters take so much current that they soon become heated to a dangerous degree if left in circuit continuously, and therefore the switch or push-button should be left open except when the instrument is in actual use. Even if the instrument does not become so hot as to endanger its insulation, its resistance changes and it becomes warm; this allows less and less current to pass through the instrument, and it then indicates a lower voltage than that actually at its terminals.

851. *Why does a voltmeter with low resistance get a poor reputation even if the switch is closed only when in actual use?*

A voltmeter with low resistance takes considerable current. If the circuit whose voltage is being measured has comparatively high resistance, the additional current taken by the voltmeter may cause an appreciably greater drop on the line, so that the voltage at the point tested may be considerably lower when the voltmeter is in circuit.

852. *Why are the division marks omitted in the lower parts of the scales of many instruments?*

Some instruments are intended for use with currents or pressures that vary only through narrow limits, and the scale is marked only on those parts to save expense. Other instruments are not accurate

for small readings, and so the scales are not calibrated below a point where the instrument becomes unreliable.

853. *Why are such instruments not reliable for small readings?* Partly because the friction of the moving parts is relatively great, and partly because many instruments depend upon the attraction or repulsion of soft iron cores, which is not constant for small currents at different times on account of hysteresis. (See No. 763.)

854. *What instruments are based upon the attraction of a core into a coil?*

Familiar examples are the ammeters used with Brush arc dynamos and those formerly sold with Edison dynamos and with Westinghouse alternators. One of the latter is illustrated in the figure, in

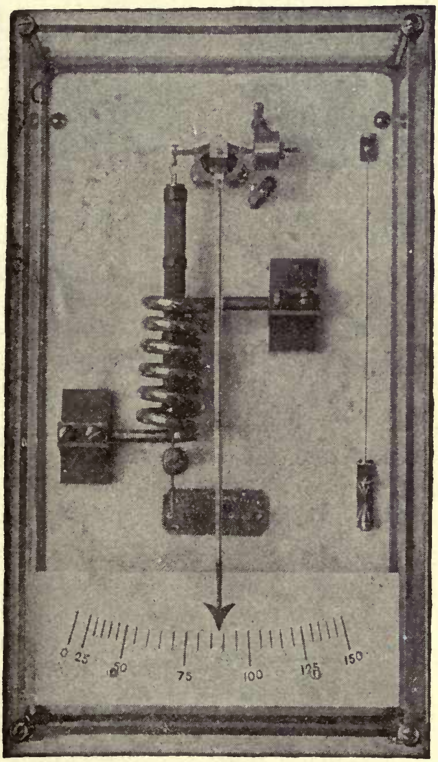


FIG. 854.—SOLENOID AMMETER.

which the bundle of fine iron wires is seen hung from one end of a sort of balance having a counterweight at the further end and a long pointer hung below.

855. *What is the principle of the eccentric instruments of Thomson-Houston and Fort Wayne companies?*

These instruments, illustrated in the figure, have a stirrup of soft iron hung eccentrically in a coil in such a way that the iron stirrup is furthest from the coil when no current is passing; when current passes through the coil, the soft iron strip becomes magnetized; the

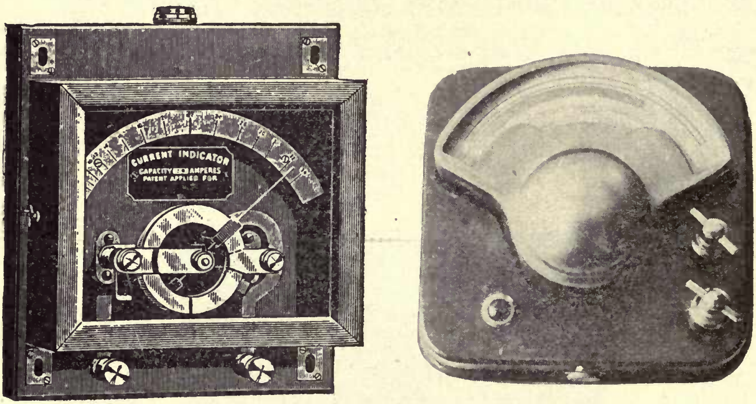


FIG. 855.—ECCENTRIC AND INCLINED COIL INSTRUMENTS.

magnetic lines of force about the coil always tend to take the easiest path; in this case, the easiest path is through the iron strip, and the path becomes shorter and easier when the strip is closer to the coil. The attraction between the coil and iron causes the iron to move so as to approach the coil, but it can only approach the coil by turning around on the pivots. The weight is so adjusted as to tend to keep the strip furthest from the coil and thus gravity opposes the attraction of the strip. These are now obsolete.

The "inclined coil" instruments of the General Electric Company are based on a similar principle, the plane of a soft iron piece being inclined from the axis of the coil and coming toward such axis as it rotates against a spring.

856. *What is the principle of the "magnetic vane" instruments?*

The magnetic vane instruments have two soft iron cores, one of which is fixed and repels the other one, which is pivoted and free to move. The two iron pieces repel each other, since they are magnetized in the same direction; also, since the repelling force is greatest when the two are closest together, the force moving the needle or pointer is considerable even with small currents, and the instrument may be calibrated from a point near the zero of the scale.

CHAPTER VIII.

ELECTRICAL MEASUREMENTS.

(Direct Current.)

900. *How is current measured?*

Current is measured by placing an ammeter or its equivalent directly in the circuit so that the current to be measured shall pass through the instrument.

901. *How is electromotive force measured?*

Electromotive force or voltage is measured by connecting a voltmeter or its equivalent to the two points whose difference of potential is desired. The common method of using the instruments is

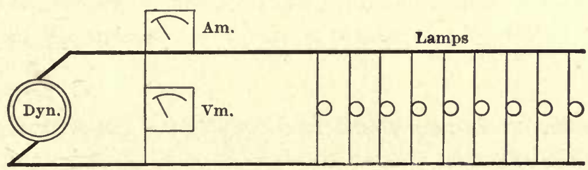


FIG. 901.—MEASURING CURRENT AND VOLTAGE.

shown in the figure, in which current from the dynamo passes through the ammeter and then through the lamps, the pressure or voltage being measured by the voltmeter connected across the line.

902. *How can one tell whether an instrument is an ammeter or a voltmeter?*

Almost all instruments are marked. If the scale is marked to read amperes, or if the name on the plate states that the instrument is an ammeter, an ampere-meter or a current indicator, one may be sure it is intended for measuring current and not volts. So, if the scale is marked to read volts, or if the name plate states that it is a voltmeter, pressure indicator or potential indicator, it is for measuring voltage and not current. If the instrument has no marks of identification, the size of the terminals or binding posts will be an indication, ammeters usually having comparatively large terminals, while voltmeters have small ones. One can generally get some idea of the

size of the conductors in the coil either by looking through the glass front or by taking off the cover. If the wire is about the size of a coarse thread or smaller, the instrument is a voltmeter or a milli-ampere-meter. If the wire is larger, the instrument is an ammeter. If the instrument has two large and two small terminals, it is a watt-meter, or possibly a combined ammeter and voltmeter.

903. *What would result if one attempted to use an ammeter for a voltmeter?*

The ammeter has so small resistance that if it were connected between two points having a considerable difference of potential, a large current would flow in accordance with Ohm's law, and would be apt to damage not only the instrument, but other parts of the circuit as well.

904. *What would result if one attempted to use a voltmeter as an ammeter?*

The voltmeter has so high resistance that it would not allow any appreciable current to pass unless the E.M.F. were very high, in which case the voltmeter would be burned out. Sometimes the voltmeter may be used as a delicate ammeter for measuring quite small currents.

905. *Is an instrument liable to injury if not connected properly into the circuit?*

Usually instruments are not injured if the polarity is reversed so that the current flows in the wrong direction. If the instrument is intended for alternating currents, of course its readings are independent of the direction of the current. If the instrument depends upon the action of a permanent magnet, the pointer simply moves in the wrong direction and goes against a stop.

906. *How can one be sure that the current will not be too much for the instrument?*

In the first place he must exercise some judgment, as a knowledge of what load is on the circuit will ordinarily enable one to estimate the probable current or voltage to be expected. He must be careful that he does not try to use an ammeter for a voltmeter or a voltmeter for an ammeter, unless he knows exactly what he is doing. If the voltmeter has two scales, he should first try the circuit with the instrument connected for use with the higher scale to learn if he can safely use the lower scale.

907. *When a voltmeter has two scales, how can one tell which terminals to use to get the right scale?*

Voltmeters with two scales usually have three terminals, one on one side of the instrument and two on the other side. The single terminal is used for both scales. One of the two terminals on the other side is usually smaller than the other, and one can easily remember that the smaller terminal goes with the smaller scale.

908. *What would be the effect of sending too much current through an instrument?*

The pointer would be thrown violently against the upper stop, with so much force that it would probably become permanently bent. If the excessive current is allowed to continue through the instrument for any length of time, it is likely to heat the wire to a dangerout temperature and destroy the insulation, or, perhaps, melt the wires. The same effects are also produced if a voltmeter is connected across a circuit of too high voltage, since that would send too much current through the coils. In the case of a static voltmeter in which no current flows, too high voltage is liable to jump across and short-circuit the instrument and the line.

909. *Is it better to close the circuit at an ammeter or at some other point in the circuit?*

The circuit should not be made or broken at the ammeter terminals, since it is not easy to close the circuit without making an uncertain contact, which causes arcing and burns the terminal. Also, it is not possible to open a circuit at the ammeter without drawing an arc, which burns and disfigures the terminal. It is a good plan to have the ammeter near a switch, that one may see what current flows at the instant the circuit is closed, so that if anything is wrong he can open the circuit before considerable damage is done.

910. *Is the reliability of an instrument affected if the terminals are burned and blistered?*

The instrument itself might not be injured at the time, but a disfigured instrument is almost sure to be looked upon as being an old one and unreliable, hence it is more liable to abuse. The man using a disfigured instrument is also sure to think that, as the instrument is a poor one, it makes little difference whether he does accurate work, since he can not depend upon the instrument, anyhow. Thus the practice of using the ammeter as a switch for closing and opening the circuit is very apt to lead to poor work from those thus using it.

911. *In what way is an instrument liable to be abused?*

By careless use as a switch, by rough handling, and by its use with excessive curents or voltages.

912. *How does rough handling injure an instrument?*

The best voltmeters and ammeters are made much like a watch, with small pivots which rotate on jewel bearings. Rough handling is apt to crack the jewels or to dull the ends of the pivots, or to spring the parts. Rough handling is also liable to weaken the permanent magnet, if the instrument has one, which will make the instrument read too low or too high.

913. *What kind of instruments read too high if the permanent magnet is weakened?*

Instruments such as the Deprez galvanometer or Blondel oscillograph (Fig. 1505), in which the pointer or mirror is attached to a piece of soft iron that is held toward the zero point by a stationary permanent magnet and is deflected by a coil, whose magnetizing effect is at right angles to that of the magnet. When the magnet becomes weak, the relative pull of a given current through the coil becomes greater, and the pointer is then deflected too far, thus making the instrument read too high.

914. *What kind of instruments read too low if the permanent magnet is weakened?*

Those like the Weston, Whitney or American, in which the coil rotates in the field of the permanent magnet. In such instruments the pull of the coil is opposed by a pair of springs. The pull of the coil is proportional to the product of the strength of the magnet and the ampere-turns in the coil. If then the magnet becomes weaker, the pull between the coil and the magnet becomes weaker for a given current, and since the strength of the opposing springs has not been affected, the instrument reads too low.

915. *Is an instrument liable to give incorrect readings even if it is in good order?*

Yes, to some extent. Most instruments are more or less affected by outside magnetic influences. Many instruments give correct readings only when approximately level or when vertical, according to the style of instrument.

916. *How does leveling affect instruments?*

Some instruments, such as the Siemens electrodynamometer (see No. 825) must be carefully leveled so that the moving coil shall hang exactly in the same position with reference to the stationary coil, for

the magnetic field of each coil varies in different positions, and it is necessary for the two to occupy exactly the same relative positions as when the instrument was calibrated. In many instruments of a more portable form the moving parts are balanced for only one position, either for horizontal or for vertical use. If the instrument is placed in any other position, the pointer is liable to stop at some other place than at the zero point, and being wrong at the starting point, every other indication of the pointer is liable to be incorrect.

917. *How are instruments affected by outside magnetic influences.*

All instruments depending upon the magnetic effect of the current are more or less sensitive to outside magnetic fields, for these either weaken or strengthen the magnetic field inside the instrument. Generally speaking, the weaker the regular magnetic field the more easily it is affected by outside disturbances. Delicate galvanometers, which depend upon the earth's magnetic field, are sometimes sensitive to the running of a dynamo hundreds of feet distant or to the return currents from a trolley car some thousand feet distant. Almost every instrument is affected if close to a dynamo or a motor. Instruments having permanent magnets are liable to affect one another unless kept at least 2 ft. apart. The magnetic field around conductors carrying heavy currents is strong enough to affect instruments of the electrodynamometer type, and sometimes even those of the d'Arsonval (see No. 834) type. In no case should instruments be placed within 2 or 3 ft. of a dynamo or a motor.

918. *How can one tell whether an instrument is being affected by a stray magnetic field?*

By turning the instrument around, the effect of the outside disturbing field will be reversed, so that if the reading was too high before, it will then be too low. The average of the two readings taken with the instrument in two positions will be close to the correct reading. If the instrument does not depend upon the field of a permanent magnet, its readings may be corrected by simply reversing the current through the instrument, instead of reversing the instrument itself.

919. *Are instruments measuring alternating currents affected by stray fields?*

That depends upon the nature of the disturbance. If the outside field is uniform in strength and direction, it will not ordinarily affect the readings of an instrument measuring alternating currents. But if the outside field is due to, or is affected by, the alternating current,

it may affect the instrument. An instrument for measuring alternating currents is liable to be affected by the field due to the current in the wires leading to and from the instrument. Such instruments are liable to be affected by eddy currents induced in any solid masses of metal that may be near the coils. Any pieces of iron near the instruments are liable to become more or less magnetized by the current, which will result in strengthening the magnetic field in the instrument itself.

920. *Do instruments calibrated for use with alternating currents give correct readings when used with direct currents?*

Instruments of the electrodynamometer type give equally correct readings with direct or alternating currents, except that they are more liable to be affected by outside magnetic disturbances when used with direct currents. Instruments having iron cores or needles give higher readings with direct than with alternating currents; with alternating currents, the higher the number of alternations the lower the reading. Electrodynamometers are independent of the frequency. The type shown in the illustration with No. 825, has been improved upon in modern instruments.

921. *How can one measure the current without opening the circuit?*

If there is a switch in the circuit in a convenient place, an ammeter may be connected around the switch; when the switch is opened, the whole current will pass through the ammeter. This method is frequently used in measuring the current in an arc-light circuit either at the station or out on the line. At the station the ammeter is shunted around one of the switchboard cables, which is then pulled out. Out on the line one may connect an ammeter to two sides of a coupling and then loosen the joint. Of course, great care must be taken not to open the circuit, and also not to make connection with the ground, for there is great danger of getting killed or of putting out all the lights on the circuit.

922. *How can the current be measured when there is no place for cutting in an ammeter?*

Either of two methods may be employed, each a "fall of potential" method. If one can secure a piece of conductor the same as that through which the current is passing, he may use a low-reading voltmeter (a millivoltmeter) and measure the difference of potential between two points of the conductor some definite distance apart, say 2 or 3 ft. The millivoltmeter is then connected between two points, an equal distance apart, on another conductor the same size

and material as the first; now send a measured current through the second conductor and adjust the current until the millivoltmeter shows the same deflection as before. Then, since the resistances of the two pieces of conductor are the same, and the fall of potential is the same in each, it follows that the current is the same. Instead of sending an equal current in the two cases, a smaller current may be taken in the second case, and the currents will then be proportional to the two readings on the millivoltmeter.

923. *How can the current be measured when a second piece of conductor is not accessible, as in the case of measuring the current in a rail?*

In such a case another modification of the fall of potential method may be used. Secure a storage cell, *S*, capable of delivering a current as large as that to be measured and have an adjustable resistance, *r*, for controlling its current. Place an ammeter, *A*, in the circuit of the cell and then fasten the terminals of the cell circuit to

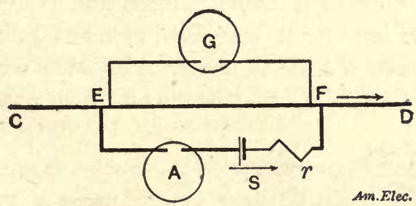


FIG. 923.—MEASURING CURRENT BY FALL OF POTENTIAL.

the rail, *CD*, or other conductor. Attach the terminals of a millivoltmeter or more sensitive galvanometer to two points, *EF*, on the rail inside of the points where the cell is attached, and adjust the current from the cell until the galvanometer gives no deflection. The fall of potential due to the original current in the rail is now exactly balanced by that due to the current from the cell, and the latter current may be measured by the ammeter. The complete theory of this method is somewhat complicated and the practice of it involves experimental difficulties.

924. *What is meant by calibrating an instrument?*

The calibration of an instrument is the process of determining the value of the current or voltage required to move the indicator to any or all parts of the scale. This may be done either in making a new scale or in checking an instrument which has been in use. The calibration may be simply a comparison with a standard instrument, or it may require the use or construction of absolute standards. (See No. 849.)

925. *How are absolute standards used?*

Absolute standards of current or E.M.F. depend upon the skilful use of chemical solutions of absolute purity and handled in accordance with certain specifications which have been adopted by government. (See Nos. 227 and 228). It is so much trouble and expense to use the absolute standards that it is more common to use first-class instruments, which were originally calibrated by reference to absolute standards, and whose calibration is checked at intervals. Any one contemplating such work should consult Gray's book on *Absolute Measurements* and *Transactions of American Institute of Electrical Engineers*, vol. 10, pp. 13 to 26.

926. *How is an ammeter calibrated by reference to a standard ammeter?*

The two instruments are connected in series, and the same current is sent through both. The current is measured on the standard instrument and the deflection of the pointer of the other is noted. The strength of the current is then changed and readings are taken on both instruments again. In this way, as many points as are desired are established and a scale is made. For such work it is desirable to use a storage battery so that the current may remain constant dur-

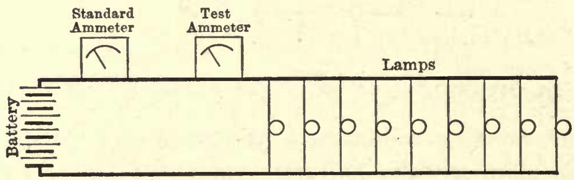


FIG. 926.—CALIBRATING AN AMMETER.

ing each set of readings. The two instruments should be placed far enough apart so that the magnetic field from one does not affect the other (see Nos. 752 to 755), and each should be carefully leveled. It is well to compare the two instruments with increasing currents and then with decreasing currents to check against errors and to see how far the instrument is affected by friction or by hysteresis (see No. 760). Instead of using a standard ammeter, a standard resistance and millivoltmeter are sometimes used for measuring the current for calibration. Low voltage is economical for such work.

927. *How can current be measured by a resistance and millivoltmeter?*

This is essentially the same as the use of a galvanometer and shunt (see No. 839). By Ohm's law (see Nos. 315 to 326) the fall of

potential or drop through a conductor equals the product of its resistance by the current passing. If then the resistance is constant and is known, the current may be calculated by measuring the voltage

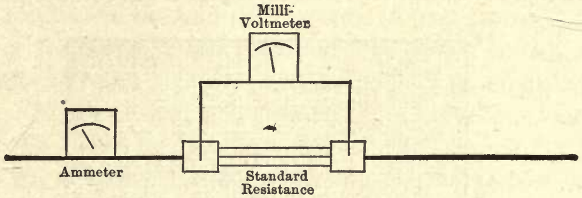


FIG. 927.—MEASURING CURRENT BY FALL OF POTENTIAL.

between its terminals. Standard resistances may be obtained with great accuracy and capable of carrying considerable currents without appreciable change of resistance.

928. *How are voltmeters calibrated?*

The simplest method is by comparing with a standard voltmeter, the two instruments being connected in multiple so that both are subjected to the same voltage, as suggested in Fig. 930. The voltage between the terminals is then changed to different values and readings on the two instruments are compared.

929. *How are the results of a calibration used?*

A new scale for the instrument may be made. A less difficult process is to construct a curve showing the corrections to be made when using the instrument. The results of the test may be left in the form of a table; but as it is necessary to find values other than those in the test, it is usually easier to get these from a curve than by interpolating from the table. Suppose that the accompanying table gives the results of a test. If in later use, the instrument should read 80 volts, the table shows that the correct pressure is 78.6 volts; if it reads 82 volts, we could add to 78.6 two-fifths of the difference between 78.6 and 83, which would make 80.36 volts. This is likely to

CALIBRATION OF VOLTMETER NO. 929

No 929 Readings	Standard Volts	Volts Error	No. 929 Readings	Standard Volts	Volts Error
10	10.2	+ .2	70	69.0	—1.0
20	20.9	+ .9	80	78.6	—1.4
30	31.3	+1.3	90	87.8	—2.2
40	40.8	+ .8	100	97.5	—2.5
50	50.1	+ .1	110	107.6	—2.4
60	59.7	— .3	120	117.8	—2.2

require a calculation each time, so that it is easier to construct a curve from which intermediate values may be taken by inspection. One method is to compute a column of differences betwen the readings of the two instruments, and then plot a curve in which horizon-

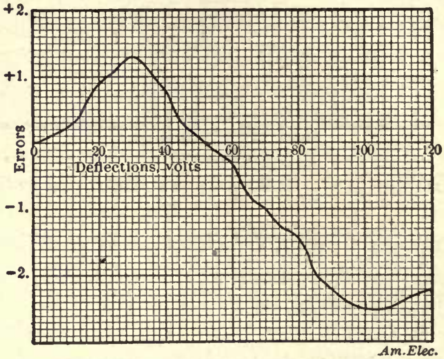


FIG. 929A.—CALIBRATION CURVE.

tal distances represent scale readings, and vertical distances show the amount to be added or subtracted to give the true value. Another plan is to draw a curve in which horizontal distances represent the indications of the instrument tested, while vertical distances rep-

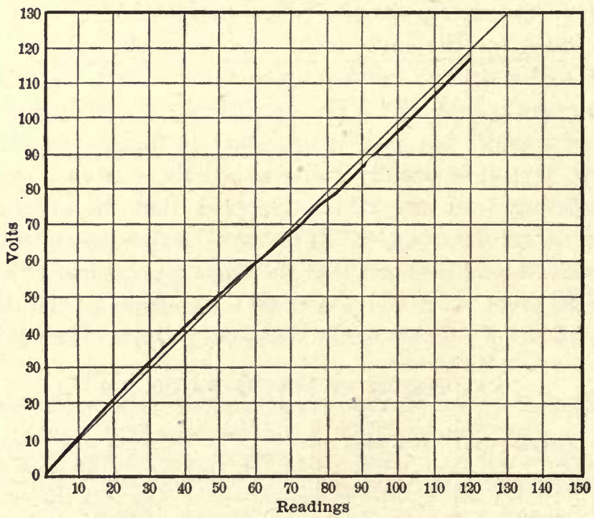


FIG. 929B.—CALIBRATION CURVE.

resent the correct values. The departure of this curve from a line drawn at 45 degs. shows the amount of correction in any part of the scale. The accompanying table and curves illustrate a case.

930. *How can different voltages be obtained for calibrating voltmeters?*

When a battery is available, a convenient method is to connect one common terminal of the two instruments to one end of the battery and moving the other common terminal from cell to cell, so as to secure as much pressure as desired between the terminals of the instruments. A more common method is to connect a suitable resistance across a constant potential circuit; for example, 15 ft. or 20 ft. of No. 30, or about 100 ft. of No. 24 German silver wire may be connected across a circuit with about 100 volts. A small current will flow through the wire, and as its resistance per foot is uniform,

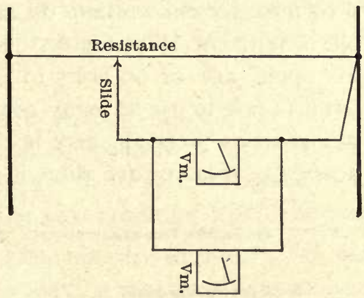


FIG. 930.—FALL OF POTENTIAL IN A WIRE.

the fall of potential will correspond. By shunting the voltmeters around more or less of this wire, any pressure desired may be obtained. It is important that the switches or push-buttons of both instruments be closed when readings are taken, for the voltage is apt to change if only one is closed at a time.

931. *How can a voltmeter be used to measure higher voltage than its ordinary range?*

The range of a voltmeter is doubled by placing it in series with an equal resistance. For example, if a voltmeter reading to 150 volts has a resistance of 20,000 ohms, it will read to 300 volts when in series with an added resistance of 20,000 ohms. This is true only for instruments that take current, and does not hold true for electrostatic instruments. The reason is that an ordinary voltmeter is really a sort of ammeter with high resistance (see Nos. 826 and 848), and if the resistance of the circuit is doubled, twice as much pressure is required to send the same current through. By having several resistances, the voltmeter may be given any range desired. Such resistances are called "multipliers" (see Nos. 847 and 932). With alternating currents, transformers are used (see Nos. 1405, 1407).

932. *What is the fractional method of measuring pressures higher than the range of a voltmeter?*

Connect in series a number of resistances, such as incandescent lamps, and couple the ends of the circuit to the line whose voltage is to be measured. There should be enough of the lamps in the string so that not too much current will pass and destroy the lamps, and, if possible, the lamps should be of the same candle-power voltage and efficiency, so as to have equal resistance. A small current will pass through the string of lamps, and, if all have equal resistances, there will be the same drop through each, so that the total voltage equals that around one multiplied by the number of lamps. The figure shows how this method may be used to measure the voltage on an arc-light circuit when only a 150-volt instrument is available. One can count on about 50 volts for an "open" arc, or 60 volts to 80 volts for an inclosed arc lamp, so that it is safe to use as many 100-volt incandescent lamps in the pressure circuit as there are arcs in the main line. To make sure that the ncandescent lamps are alike, it is well to measure

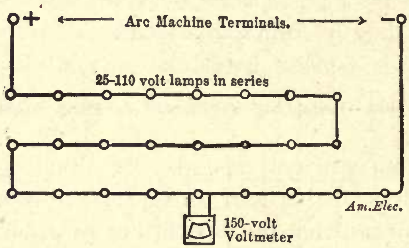


FIG. 932.—MEASUREMENT OF HIGH VOLTAGE.

the voltage around each one separately and take the sum as the total voltage. A lamp whose pressure is close to the average may then be adopted for a standard, and the voltage around that lamp multiplied by the number of lamps gives approximately the whole voltage. This method is subject to two sources of error: the total pressure may vary during the test, and the pressure around each lamp is slightly less when the voltmeter is around it than at other times. The latter error is not more than 1 per cent or 2 per cent with fairly good voltmeters, which take but little current.

933. *How can a voltmeter be used to measure a voltage lower than its smallest reading?*

With an instrument with two or more scales (see No. 847), the measurement may sometimes be made by using the lower scale. It is sometimes practicable to get into the instrument and make another

connection so as to obtain a scale lower than that sent, but this involves risk of injuring the instrument. When the scale is open near the lower end, a small voltage may frequently be measured by placing it in series with another, which will bring the reading near the most open part of the scale. In that case the small voltage equals the difference in the two readings, when it does and does not increase the reading with the auxiliary voltage alone. For example, suppose it is desired to measure the voltage of a small battery when the only instrument available reads nothing less than 15 volts. Connect one side of the battery to one wire of a dynamo circuit; connect the voltmeter first across the dynamo circuit and then across the dynamo and battery. Suppose, in the first case, it reads 106 volts, and in the other, 107.8 volts or 104.2 volts. The battery, therefore, adds or subtracts 1.8 volts.

934. *Is the above method suitable for alternating currents?*

It is not so reliable as with direct currents, for the two alternating pressures are liable not to be in exact phase, in which case the difference between the two readings would be too small.

935. *What instruments are necessary for measuring resistance?*

High resistances may be measured by a voltmeter, by a bridge or by an ohmmeter. Low resistances may be measured by an ammeter and a voltmeter, or by a voltmeter and standard resistance. There are other methods suitable for laboratories with fine apparatus and skilled operators, but most measurements of resistance for practical purposes can be made with the apparatus mentioned.

936. *How can resistance be measured with a voltmeter?*

For this purpose a voltmeter of known resistance and a dynamo or battery giving constant voltage are necessary. First connect the voltmeter directly to the terminals of the dynamo, as suggested at *A* in the figure, or to some circuit connected with it, on which the current is not changing. Carefully measure the voltage between the lines,

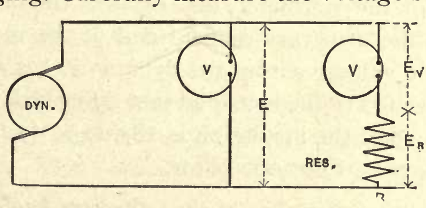


FIG. 936.—MEASURING RESISTANCE WITH VOLTMETER.

and then connect in series the resistance which is to be measured, as shown at *B* in the figure, and again read carefully the voltage

indicated on the voltmeter. This reading will be smaller than the first, because the resistance of the circuit is greater and less current goes through the voltmeter than before. Ohm's law, that current equals voltage divided by resistance, is equally true if turned around to read that resistance equals voltage divided by current. Now, when the same current flows through two resistances, the voltage or fall of potential through each is proportional to the number of ohms resistance in each. In the case above, the drop through the voltmeter is evidently the reading of the voltmeter, while the difference between that reading and the first one taken when the voltmeter was connected directly across the circuit is the voltage drop through the resistance being measured. This may be expressed as follows: The resistance being measured equals the resistance of the voltmeter multiplied by the difference between the two readings and divided by the smaller reading.

937. *Give an example of measuring resistance by a voltmeter.*

Suppose we wish to measure the resistance of the field coil of a ½-kw, 125-volt motor. The voltmeter has a resistance of 18,000 ohms. When connected directly to the circuit, it indicates 125 volts; when connected in series with the field coil of the motor, it reads 121 volts. (Of course, in this measurement, it is necessary to place the voltmeter a sufficient distance from the motor so that its magnetic field will not influence the voltmeter). The resistance of the motor field is then $18{,}000 \times (125 - 121) \div 121 = 595$ ohms.

938. *How can a voltmeter be used to measure insulation resistance?*

By connecting one side of the circuit with one side of the dynamo and connecting the other to it through the voltmeter. For example, suppose it is desired to test the insulation between the frame and the windings of the motor. Connect the frame of the motor to one side of the dynamo circuit; connect the other side of the dynamo circuit to one terminal of the voltmeter, and connect the other terminal of the voltmeter to the armature or field coil of the motor. Suppose, as before, that the voltage across the dynamo is 125 volts; when the voltmeter is connected to the motor as just described, it reads 2 volts. Then the resistance of the insulation is $18{,}000 \times (125 - 2) \div 2 = 18{,}000 \times 123 \div 2 = 1{,}107{,}000$ ohms.

939. *How can the resistance of the voltmeter be determined?*

The best instruments have the resistance marked on the case or on the box. If this is not found, it can be determined easily if one can get some high resistance of known value. As before, first meas-

ure the voltage across the line, and then connect the high resistance of known value in series with the voltmeter. The resistance of the voltmeter equals that of the other multiplied by the second reading and divided by the difference between the two.

940. *Give an example of determining the resistance of a voltmeter by means of a known resistance.*

Suppose that the voltmeter reads 125 volts when connected directly across the line, but only 75 volts when in series with a resistance of 10,000 ohms. The resistance of the voltmeter is then: $10{,}000 \times 75 \div (125 - 75) = 750{,}000 \div 50 = 15{,}000$ ohms.

941. *What range of resistances can be measured satisfactorily with a voltmeter?*

It depends largely upon the range and the resistance of the voltmeter. With a Weston 150-volt instrument one can measure from about 100 to 2,500,000 ohms, the greatest sensitiveness and accuracy being for resistances about equal to that of the voltmeter. With one having a range from 0 to 5 volts, one can measure resistances from about 3 to 85,000 ohms.

942. *How can one measure resistance with an ammeter and a voltmeter?*

Connect the ammeter in series with the resistance to be measured and connect the voltmeter in shunt around it, as shown in the figure.

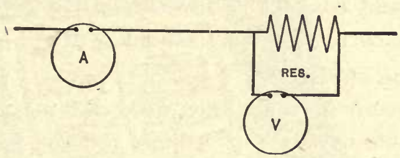


FIG. 942.—MEASURING RESISTANCE BY AMMETER AND VOLTMETER.

By Ohm's law, the resistance equals the current divided by the voltage.

943. *Give an example of measuring resistance by an ammeter and a voltmeter.*

Suppose the current through one of the field coils of an arc dynamo is 10 amps., while the voltmeter shows 20 volts when connected around the coil. The resistance of the coil is then: $20 \div 10 = 2$ ohms.

The voltmeter connected around an arc lamp in the same circuit shows 45 volts. The apparent resistance of the arc lamp (including the arc) is: $45 \div 10 = 4.5$ ohms.

944. *What precautions are necessary to insure accuracy when measuring resistance with a voltmeter?*

Be careful that the voltage of the dynamo or battery does not change between the two readings; this can usually be checked by taking a second reading across the line with the voltmeter alone. Be sure also that the voltmeter is not affected by any magnetic field from the circuit being measured. Also be sure that the wires and connections used do not have any appreciable resistance, or that must be considered.

945. *What precaution should be taken when measuring with ammeter and voltmeter?*

Be careful that neither instrument is affected by magnetic field from the other instrument or from any other source. Be careful not to use more current than is suitable for the resistance being measured. Be careful about the connections, especially those at the terminals of the resistance which are to be measured, for if these are not good the voltmeter will read too high. There is a small source of error in the fact that if the voltmeter is connected inside the ammeter, the ammeter measures the current through the voltmeter as well as that taken by the resistance; on the other hand, if the voltmeter is connected behind the ammeter it measures not only the drop through the resistance, but also that through the ammeter, and through the connections. It is usually better to neglect the current in the voltmeter and connect it directly to the terminals of the resistance. Suitable corrections can be made without great difficulty.

946. *What is an ohmmeter?*

This is an instrument sometimes used for measuring resistance where it is desirable to test with a high voltage, but where none is available except as supplied by the testing outfit. It consists of two

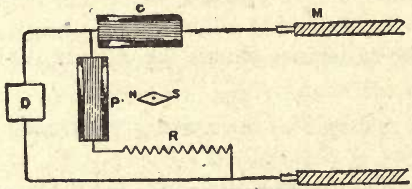


FIG. 946.—OHMMETER.

parts, a small hand dynamo capable of generating 100 volts or more, and the instrument proper. The latter has two coils at right angles to each other, and a magnetic needle, which takes a position between the two coils according to the relative currents in the coils One coil is connected between the dynamo and one terminal of the circuit whose resistance is to be measured; the other coil is connected in series with a high resistance inside the instrument so as to form a

shunt across the main circuit, as shown in the figure. When the dynamo is operated, the current divides, part going through the coil, *C*, and then through the main circuit, whose resistance is to be measured, while the remainder goes through the coil, *P*, and the high resistance, *R*. The currents through the two coils are inversely proportional to the resistances in their circuits, since the same voltage is applied to both, and therefore they attract the needle correspondingly. For a given voltage of the dynamo, the attraction of the coil, *P*, is constant, while the attraction of coil, *C*, becomes greater as the resistance in the main line becomes less. The pointer attached to the needle will therefore move toward *C* as the resistance in the line becomes less, and the scale may be divided to indicate the resistance in the main circuit.

947. *For what range of resistance is the ohmmeter suitable?*

It will measure resistances from about 5 megohms (5,000,000 ohms) down to about 1000 ohms. It is convenient for measuring the insulation resistance of wiring in houses that are not yet connected with the supply circuit.

948. *What is a Wheatstone bridge?*

The Wheatstone bridge is an arrangement of resistances with a battery and galvanometer for measuring resistances. It usually con-

FIG. 948A.—WHEATSTONE BRIDGE.

sists of two "proportional arms" of such values that one arm has one, ten, one hundred or one thousand times the resistance of the

other arm. The third arm is divided into tenths, units, tens, hundreds and thousands of ohms. The resistance to be measured becomes the fourth arm. When the bridge is balanced, the unknown resistance has the same ratio to that of the divided arm as one of the proportional arms has to the other.

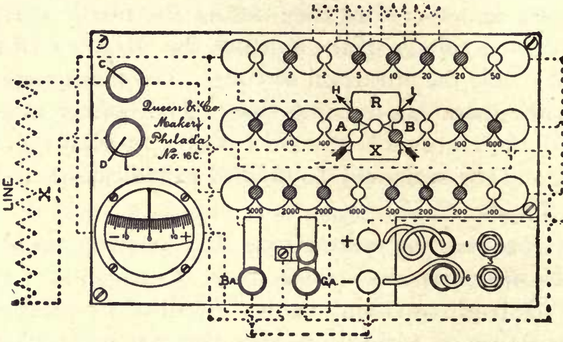


FIG. 948B.—WHEATSTONE BRIDGE.

949. *What is the theory of the bridge?*

Suppose we have two conductors connected in multiple, and having a battery or other source of current applied to their terminals. The potential would fall from one end to the other in each wire, and for any point in one wire a corresponding point in the other can be found at which the potential has fallen the same amount. If a galvanometer is connected between these two points, no current will flow since there is no difference of potential between its terminals. We have a close analogy in the case of a river which divides and flows around an island; the water at every point along a line across the river at the head of the island is at the same level; also every point in another line across the river at the lower end of the island is at the same level; if the water flows along the two sides of the island without any sudden falls, for any point on one side of the island, we may find a corresponding point on the other side which has the same level; between these two points no current would flow if a canal were dug between the two. In the Wheatstone bridge the galvanometer circuit corresponds to the canal across the island, and when no current flows through the galvanometer it shows that the two ends of the circuit have the same potential. If then we know that one end of the canal is one-tenth of the total fall from the upper to the lower level, we are sure that the other end is at a corresponding point.

950. *Give an example illustrating the principle of the bridge.*

The principle of the bridge may be explained by assuming resistances connected as in Fig. 950A with battery giving 11 volts between A and C. The currents in the various circuits are determined by Ohm's law:

$$\text{Current in circuit ABC} = I' = E/R' = 11/(45 + 10) = 11/55 = 0.2 \text{ ampere};$$

$$\text{Current in circuit ADC} = I'' = E/R'' = 11/(90 + 20) = 11/110 = 0.1 \text{ ampere}.$$

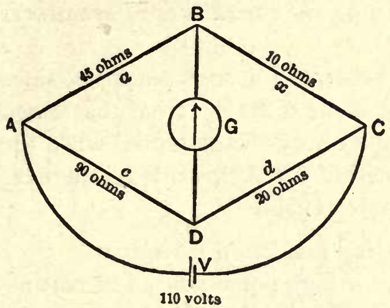


FIG. 950A.—PRINCIPLE OF BRIDGE.

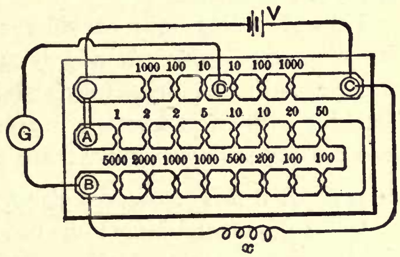


FIG. 950B.—WHEATSTONE BRIDGE.

The fall of potential or "ohmic drop" in parts AB and AD is:

$$\text{Drop A to B} = s\ e' = I'r' = 0.2 \times 45 = 9 \text{ volts};$$

$$\text{Drop A to D} = s\ e'' = I''r'' = 0.1 \times 90 = 9 \text{ volts}.$$

Since drops A-B and A-D are equal, there is no difference in potential between B and D, hence no current flows through the galvanometer G. Similar calculations would give a balance for CB and CD. For this condition of balance,

$$a \times d = c \times x, \text{ or } x = a \times d/c.$$

In practice, the resistances of the two wires, *c* and *d*, are fixed in a certain ratio for a given measurement (in this case, 20 : 90, but usually as 10 : 100 or a multiple of 10), and the value of *a* is varied until a balance is obtained. A commercial Wheatstone bridge is shown herewith, with the parts lettered to correspond to the above, *x* being the resistance under measurement. In this case, *c* is the left part of the upper row, *d* the right part, and the two lower rows correspond to *a*. If *c* were plugged for 1000, and *d* for 10, and if 1425 plugged in *b* brought a balance, then the value of *x* would be 14.25 ohms.

951. *Is it safe to use a bridge on a 110-volt circuit?*

Such a voltage would send too much current through the bridge and damage it. It is customary to use a battery giving 2 to 4 volts, although in measuring high resistances, it is sometimes desirable to use higher voltages. The current should be kept on only a very

short time, in order to avoid heating the bridge and so changing its resistances.

952. *What range of resistances can be measured conveniently with a bridge?*

It depends largely upon the bridge and the galvanometer. The best bridges will measure from 0.000001 to 111,000,000 ohms. Ordinary portable bridges will measure from 0.01 to 1,100,000 ohms with fair accuracy.

953. *Are bridges suitable for testing the resistances of armatures of large dynamos?*

They are not usually considered accurate for such purposes, since the resistance when running is apt to be different from that when standing still; such resistances should always be measured when the machine is hot and carrying current, and for such work an ammeter and a low reading voltmeter are more reliable.

954. *Is a bridge suitable for testing insulation resistance?*

Not if the insulation is to be used for high potentials. The reasons for this are two: Insulation for high potentials should be tested not so much for ohmic resistance as for its ability to stand the high potentials; again, the resistance with a low potential may be quite different from that with a high potential, on account of the electrostatic attraction between different parts bringing them closer together.

955. *How can a circuit be tested by a magneto?*

By connecting the magneto to the circuit and turning the crank; if the resistance is not too high, or if the circuit has enough electrostatic capacity, the bell will ring. (See Nos. 115, 1125 to 1131.)

956. *How can resistance be measured by means of a standard resistance and voltmeter?*

The circuit whose resistance is to be measured is connected in series with a standard resistance, that is, a conductor whose resistance is already known, and a steady current is sent through both. The voltmeter is connected first around one resistance and then around the other, as suggested in the figure. Since the same current flows through both conductors, the voltage or fall of potential through each is proportional to its resistance, and we may write the equation: current equals voltage around standard divided by its resistance; also equals voltage around conductor being measured divided by its resistance, or

$$C = \frac{E_s}{R_s} = \frac{E_x}{R_x}.$$

From this we get: Resistance of conductor being measured equals the voltage around it multiplied by the resistance of the standard and divided by the voltage around the standard, or

$$R_x = \frac{E_x R_s}{E_s}.$$

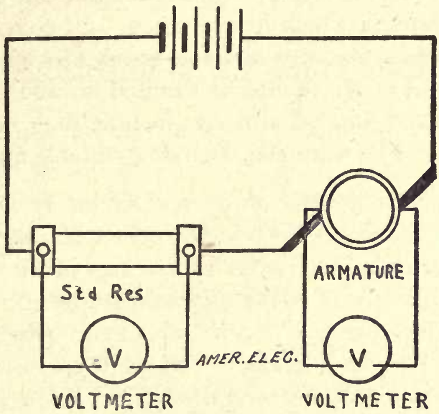


FIG. 961.—MEASURING RESISTANCE BY FALL OF POTENTIAL.

957. *Give an example of measuring resistance by use of voltmeter and standard resistance.*

Suppose it is desired to measure the resistance of a 4-kw dynamo. A standard resistance of 0.01 ohm is connected in series with the armature and a current of, say, 24 amps. is sent through both. The voltmeter shows 0.24 volt when connected around the standard. The terminals of the voltmeter are then pressed against the same commutator bars, against which the brushes rest (the armature being held stationary) and the drop through the armature is measured; the armature is then turned to a new position and the voltage is again measured between the commutator bars under the brushes; this is repeated for several positions. Suppose the average is 5.0 volts. The resistance of the armature is then:

$$R_x = \frac{E_x R_s}{E_s} = \frac{5.0 \times 0.01}{0.24} = 0.208 \text{ ohms.}$$

958. *What precautions are necessary for accuracy in measuring resistance by standard resistance and voltmeter?*

The standard resistance must be suitable for carrying current of considerable magnitude without appreciable heating; ordinary standard resistances consist of fine wire wound closely on spools with

little chance for cooling, and such can safely carry only small currents without undue rise of temperature. The "shunts" used with Weston switchboard ammeters are suitable for such use. One should be careful that the current does not change while the voltages are being measured. The voltmeter should have fairly high resistance so as not to divert an appreciable amount of current from the conductor around which it is shunted. Of course the voltmeter should give correct readings and the standard resistance should be reliable. The voltmeter should be shunted around the resistance to be measured, care being taken not to include the connections or any other resistance. The voltmeter should be suitable for small voltages.

959. *How can a ground on an arc circuit be located when the lamps are lighted, using a bank of incandescent lamps?*

Connect in series by bare wires two strings of incandescent lamps, each having half as many as the total number of arcs in series, using 110-volt lamps to represent "open" or 50-volt arcs, or 220-volt (or twice as many 110-volt) lamps to represent enclosed arcs; connect each dynamo terminal to one end of a string through a safe switch; connect the other ends of the lamp strings to switches by which either or both may be grounded; to the ground connect one end of an insulated No. 14 cable long enough to reach the length of each string of incandescents, and having a terminal wire tip with an insulated handle. To test the circuit, connect one lamp string to the ground; if the lamps do not glow, disconnect that string and ground the other; if neither string glows when grounded alone, the line is free from grounds. If one or both strings glow, ground both of them, when one string will glow more brightly than the other; beginning at the grounded center, touch the cable tip to one lamp junction after the other, until a place is found where the lamps (except those between the tip and the ground) are equally bright; the number of lamps between the tip and the dynamo terminal then represents the number of arc lamps between that terminal and the ground.

CHAPTER IX.

ELEMENTARY MOTORS.

1000. *What are the fundamental principles upon which the electric motor operates?*

Every current is surrounded by a magnetic field of force which distorts any other magnetic field in the vicinity; the two combine into a resultant field whose lines of force tend to become as short as possible, thereby tending to move both sources to a new arrangement, such that the lines may be as short as possible. In accomplishing this result, what is called the "field" is usually the space between the poles of an electromagnet; the current is in wires carried on or near the surface of a cylinder of laminated iron, the combination of iron and wire being called the "armature."

1001. *Are alternating-current motors based upon the same principles as those for direct currents?*

The fundamental principles are the same, although in the application there are many differences. With direct-current motors the currents for both the field and the armature are taken from the external circuit; with most of the motors for alternating currents the field is magnetized by current taken from the external circuit, while the current in what corresponds to the armature is often obtained by induction.

1002. *Will an alternating-current motor work upon a direct-current circuit?*

A few small alternating-current motors will work on a direct current, but most of the larger ones will not.

1003. *Will a direct-current motor work upon an alternating current?*

Almost any direct-current motor will run when an alternating current is sent through it; but it will not ordinarily develop any considerable amount of power, unless wound specially for the purpose, and unless the field magnets are made of laminated iron and precautions are taken to avoid induced currents in stationary parts of the motor.

1004. *What is the simplest form of motor?*

Those in which the wires or iron parts change their position under the action of the current so as to reduce the reluctance of the magnetic circuit. Such elementary motors generally have a movable piece of soft iron, called a "keeper" or "armature," which is attracted against gravity or a spring by the action of the current, and moves closer to the poles of the magnet so as to improve the magnetic circuit. In some cases the action of the current in the coil is to lengthen the path of the lines of force, and their tendency to shorten brings the coil into a new position, as in the instruments of the d'Arsonval type (see Nos. 833 to 836). Many of the measuring instruments (see Nos. 822 to 840) are elementary motors.

1005. *What are common examples of simple motors based on the attraction between a magnet and piece of iron?*

The telegraph sounder or relay, the telephone receiver and the electric bell are familiar examples.

1006. *Explain the action of the telegraph sounder.*

The current passes through the two coils, magnetizing the iron core and attracting the soft iron armature or keeper. When the current stops for an instant, the magnetic pull becomes less and the spring pulls the armature away. The current is interrupted by keys, by which the operator closes and opens the circuit and so causes the magnets to attract the armatures longer or shorter times. In the receiving instrument, commonly used, the message is read from the noise made by the armature as the lever or hammer strikes upon the anvil or adjusting screws. The "dots and dashes" of the recording instruments are distinguished by the longer or shorter sounds of the armature, the sound of the "dashes" being somewhat louder that that for the "dots," as the current is on longer and magnetizes the iron more strongly. The circuit for a short line is

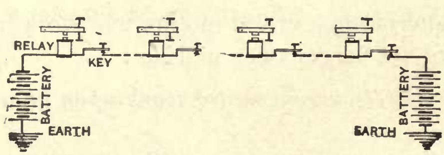


FIG. 1006.—TELEGRAPH CIRCUIT.

indicated by the figure. When the line is a long one connecting a number of stations, it is customary to use relays in connection with the sounders, the relays, keys, line and batteries, forming the circuit with the earth as the return, as indicated by Fig. 1006.

1007. *Explain the relay.*

The relay is a special form of telegraph receiving instrument. The resistance of long lines with their numerous instruments and long wire is so large that it would be almost impossible to send enough current to work the sounders with sufficient force to be heard distinctly if there was any disturbing noise. In order to make the signals intelligible, even in noisy offices, it is customary to have a relay in the main line. The current is strong enough to move the armature back and forth to close or open the "local circuit," which consists of a battery and sounder, as indicated in the figure. In this way the noise is multiplied. The relay magnets are wound with many turns of fine wire to a resistance of 30 to 300 ohms, while sounders have from 10 to 50 ohms.

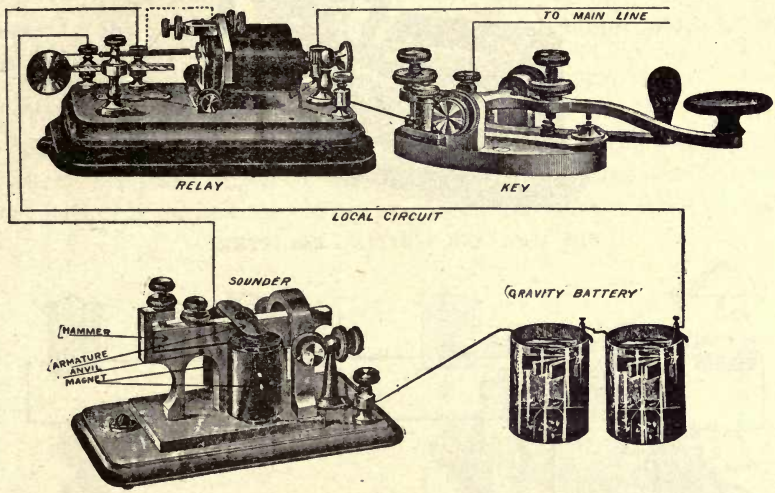


FIG. 1007.—TELEGRAPH CIRCUIT.

1008. *How are recording telegraph receivers made?*

These carry a strip of paper which passes over an ink roller or a sharp point, so that at each stroke of the armature a long or short mark is made on the paper. The figure shows a common type of ink-writing register, such as used in fire and district telegraph offices. These have a clockwork mechanism for feeding the paper, and usually have attachments for starting and stopping the paper, so that it feeds only when the receiver is operating. In the case of ocean cables, the current is so very weak that a specially sensitive receiver

is arranged so as to operate with very little friction, the ink being squirted against the paper by electrostatic repulsion (see No. 91) or jolted against it by an electromagnetic vibrator.

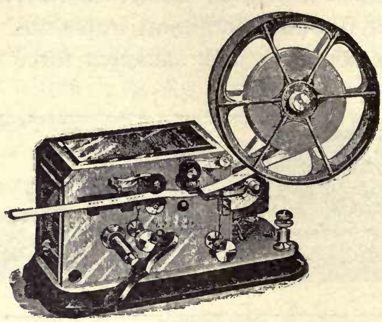


FIG. 1008A.—INK WRITING REGISTER.

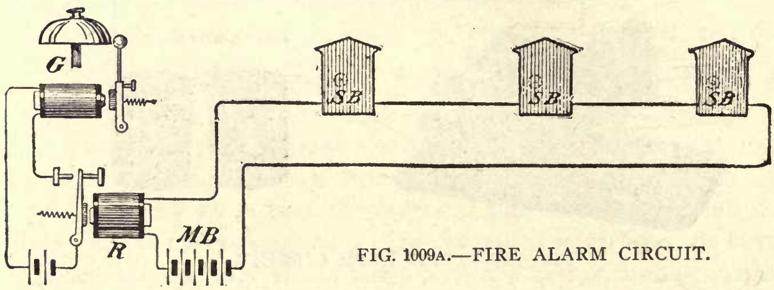


FIG. 1009A.—FIRE ALARM CIRCUIT.

1009. *How are fire alarms operated?*

The fire alarm system is practically a telegraph circuit, in which

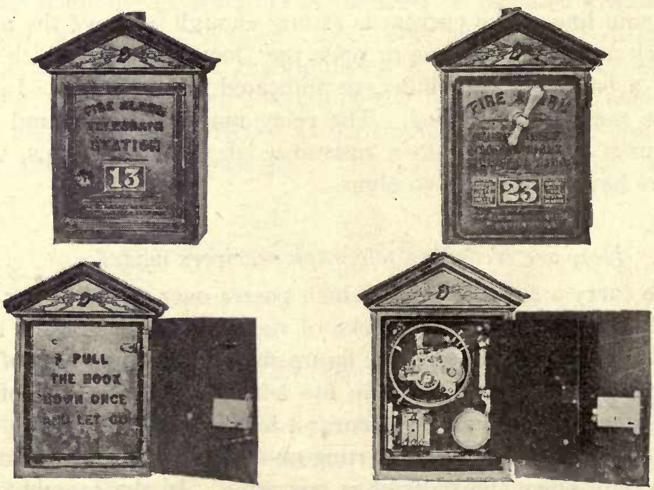


FIG. 1009B.—FIRE-ALARM SIGNAL BOXES.

the keys are replaced by notched wheels so arranged as to break and make the circuit some definite number of times, a weight or spring in the alarm box causing the wheel to revolve whenever the door is opened, and the lever is pulled down once and let go. At the central office of the fire department is a relay in each circuit, arranged to repeat the alarm at each station house, where another relay operates the gongs and rings the tower bell. A simple alarm circuit is shown in the figure.

1010. *Explain the principle of the electric bell.*

An electric bell outfit consists of four essential parts, the bell, the battery, the push-button or switch, and the connecting wire. When the button is pushed the circuit is closed, and current from the bat-

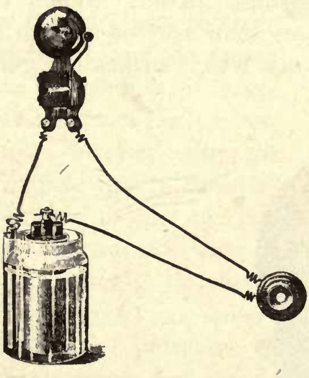


FIG. 1010-1.—ELECTRIC BELL CIRCUIT.

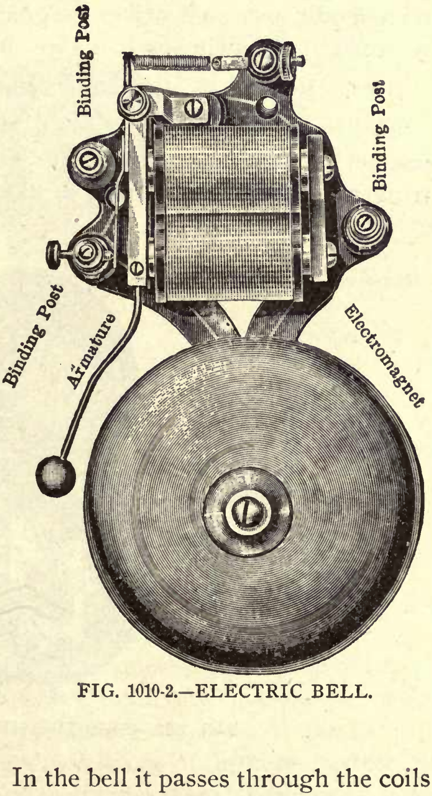


FIG. 1010-2.—ELECTRIC BELL.

tery passes through the circuit. In the bell it passes through the coils of an electromagnet, thereby magnetizing its soft iron core. This attracts the soft iron armature and draws it closer to the coils, and thus the hammer at the end of the armature strikes the bell. But

when the armature is drawn up, the spring behind it is drawn away from the contact screw, and thus opens the circuit and stops the current. This causes the iron core to lose its magnetism, so that it can no longer hold the armature against the pull of the tension spring. The armature, therefore, falls back until its spring touches the contact screw, when the circuit is closed again, and the same action is repeated. Thus the armature oscillates back and forth, opening and closing the circuit automatically, and we have an elementary motor, which operates so long as the circuit is closed at the push-button or switch. The principal parts of the bell are shown in Fig. 2.

1011. *What is a "single stroke" electric bell?*

The vibrating contact is removed so that there is no automatic make-and-break in the bell itself. The armature is therefore attracted only once, and strikes the gong one blow each time the circuit is closed at the switch. It is thus suitable for giving signals.

1012. *What is an electro-mechanical bell?*

Electro-mechanical bells are usually single stroke. When the magnet attracts its armature, this releases some sort of a catch or trigger that sets free a train of clockwork which strikes the gong

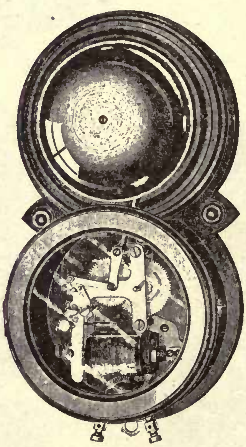


FIG. 1012.—ELECTRO-MECHANICAL GONG.

a harder blow than would be practicable with the magnet alone. The electromagnet thus acts as a sort of relay or starter, while the blow on the gong is struck by a mechanism driven by a spring or weight.

1013. *What is a buzzer?*

A buzzer is electrically the same as an ordinary electric bell, except that there is no gong. The armature vibrates rapidly and makes a buzzing noise that is sufficient to attract the attention of a person near by.

1014. *How does the telephone receiver operate?*

The telephone receiver is an elementary motor operated by an electric current which very rapidly changes its strength and usually its direction. The air is thrown into sound waves by the vibration of a thin iron diaphragm which is attracted with varying strength by one or both poles of a permanent magnet. The pulsating current from the telephone transmitter (see No. 347) is usually sent through an induction coil or transformer (see Nos. 1404 and 1405) which delivers an alternating current of high voltage, suitable for passing over long lines; this current in going through the coil of the telephone receiver increases and decreases the proportion of magnetism from the permanent magnet through the pole tips to the diaphragm, so that the latter is attracted more or less strongly; it therefore vibrates in unison with every pulsation of the current, and hence in unison with the telephone transmitter and with the voice.

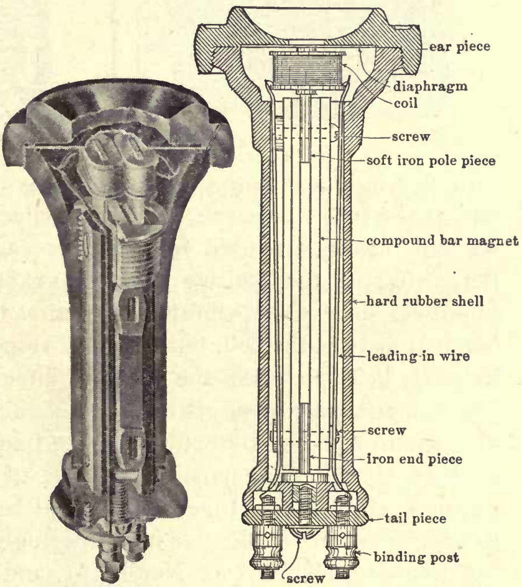


FIG. 1014.—TELEPHONE RECEIVERS.

1015. *How does the magneto bell operate?*

The magneto bell, sometimes called a ringer, operates by the action of an alternating current on a pair of iron cores and vibrator which form parts of the circuit of a permanent magnet. When the current is in one direction, the magnetism in one of the cores is strengthened and that in the other is weakened or reversed; the vibrator moves in one direction or the other, so as to carry the magnetic lines from the pole of the permanent magnet through the core which at that

moment is magnetized by the current in the same direction as by the permanent magnet; when the direction of the current changes, the vibrator is attracted toward the other core. In the magneto bell, the vibrator carries an arm and hammer which strikes one of two bells at each change in direction of the current.

A magneto bell may be arranged for "selective ringing" by at-

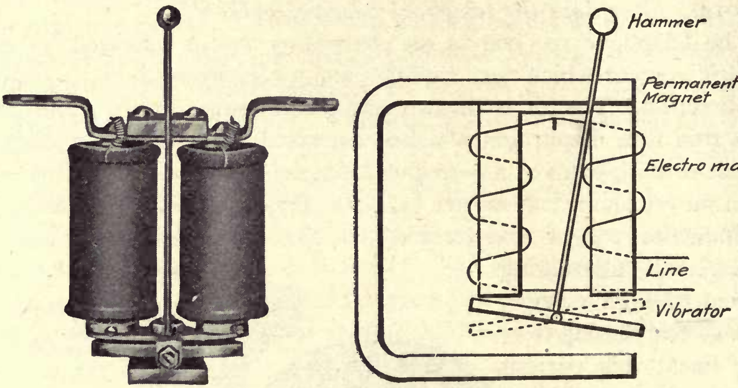


FIG. 1015.—MAGNETO RINGER.

taching a light spring to the vibrator so as to hold it normally against one of the bells; pulsating currents (halves of alternating currents, see No. 1401), are used for selective ringing; bells "biased" by the spring on the positive side are unable to respond to positive impulses, since their vibrators are already on that side with the hammer against the bell, but they will respond to negative impulses; likewise, bells biased in the opposite direction will respond only to positive impulses; by adjusting the natural period of the bell, it may be made to respond to impulses of one frequency but not to those of another, thus making possible the use of several frequencies; for example, eight biased tuned bells might be connected to one circuit to which positive or negative impulses might be applied at any one of say four frequencies (see No. 1435), and yet only the desired one would ring.

1016. *How does a pole-changer operate?*

A pole-changer is a device for obtaining alternating or pulsating currents from a battery or other source of direct current, for the purpose of ringing telephone bells. The details vary in different types, but the general principle is that of a vibrating bell (see No. 1010) whose armature opens and closes a number of contacts which are essentially a reversing switch. By this means each terminal of a line is connected alternately with the positive and negative termi-

nals of a battery for obtaining alternating currents; or the line terminals are connected intermittently with the same battery terminals to obtain pulsating current for selective ringing (see No. 1015). Some instruments have an adjustable weight on the vibrator, by

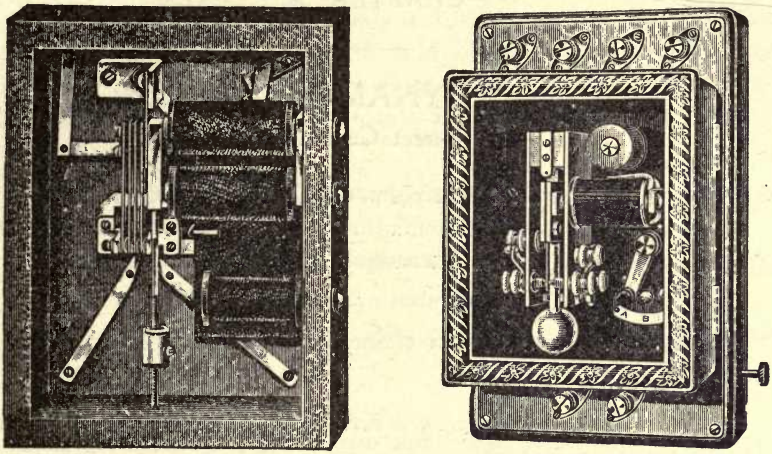


FIG. 1016.—POLE CHANGERS.

which its period and the number of impulses or alternations per second may be adjusted.

1017. *How does an electric counter operate?*

The armature of an electromagnet is attached to a pawl and

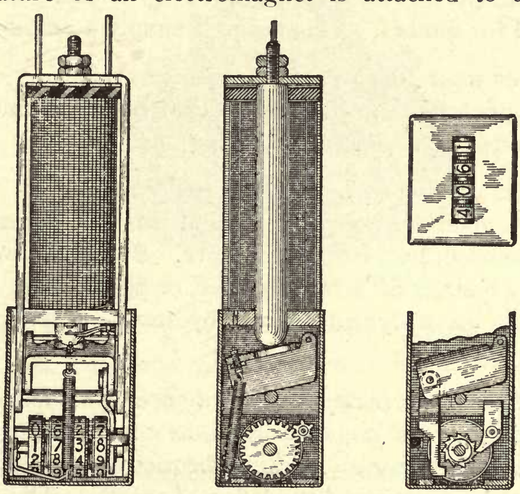


FIG. 1017.—ELECTRIC COUNTER.

ratchet which drive a counting train of gears. The pawl turns the ratchet wheel one notch each time current is sent through the magnet coils.

CHAPTER X.

DYNAMOS.

(Direct Current.)

1100. *What are the principal sources of electrical currents?*

Dynamos (often called generators), chemical cells or batteries (see Nos. 601 to 636) and thermopiles (see Nos. 400 to 406.)

1101. *What is a dynamo?*

A dynamo is a machine for changing mechanical power into electrical power.

1102. *What is the difference between dynamo-electric machines, dynamos and generators?*

The word "dynamo" is simply a shorter term for "dynamo-electric machine." The word "generator" is more general and may refer to a dynamo or to a battery, or any other source of electricity. It is common to use the word "dynamo" when the current is used for operating electric lights, and the word "generator" when the current is used for motors. This usage is simply a custom.

1103. *For what purposes are dynamos used?*

For any purpose requiring any considerable amount of energy, such as electric lights, motors, welding, etc.

1104. *Are dynamos cheaper than batteries?*

It depends upon the amount of current needed. Where only small amounts are used, batteries are cheaper. But if the work requires as much as a quarter of a horse-power, or perhaps less, it is cheaper and easier to use a dynamo driven by steam, water, or any other convenient power.

1105. *How is electricity generated in a dynamo?*

The exact action is not entirely understood, although enough is known about it to construct working theories and to design machines with accurate and positive knowledge of results. The fundamental principles are that an electromotive force is induced by every change in the number of lines of magnetic force enclosed by a circuit, and that an electric current is surrounded by a magnetic field.

1106. *If the presence of electric current produces a magnetic field, does the presence of a magnetic field produce electricity?*

The mere presence of a magnetic field around a conductor does not produce electricity, since that would imply the actual creation of energy, which is impossible. It is true, however, that the movement of a conductor across a magnetic field, or of a magnetic field across a conductor, always causes a tendency for current to flow in the conductor. If the conductor forms a closed or complete circuit, a current will flow in it.

1107. *Is there any special name for such a tendency for current to flow?*

It is called an induced electromotive force, or E.M.F.

1108. *How can one study the induction of currents?*

Much can be learned by simple experiments with galvanometer and coil of wire.

1109. *What is a galvanometer?*

The galvanomenter is an instrument for detecting or measuring small currents. A convenient one may be made by wrapping a number of turns of wire around a pocket compass (say 40 turns of No. 24 cotton-covered wire) and placing it level, and so that the needle lies in the plane of the coil. The compass needle may be in-

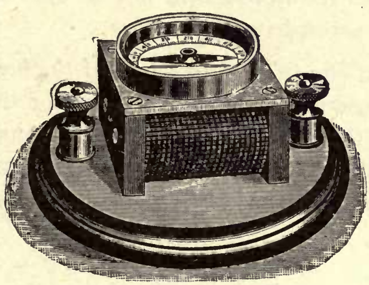


FIG. 1109.—DETECTOR GALVANOMETER.

side the coil or may be above it, as in the "detector galvanometer" illustrated. Such a crude instrument can not compare with the expensive ones in laboratories, but it will do for some purposes. (See No. 834.)

1110. *How can induction be studied with galvanometer?*

Make a coil 2 ins. or 3 ins. in diameter with forty or more turns of insulated copper wire of any convenient size. Connect the ends of the coil with the terminal wires of a galvanometer as suggested in the figure. Slip the coil quickly over the end of a magnetized

screwdriver or any other magnet and the needle of the galvanometer will be thrown to one side, say to the right, and will then return to its former position. Move the coil quickly off the screwdriver

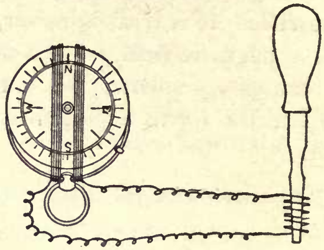


FIG. 1110.—INDUCTION.

and the needle will be thrown in the opposite direction, to the left. Twist the coil half-way around and slip it over the end of the magnet and the needle is thrown to the left. Slip the coil clear over and off at the other end, and the needle is thrown in one direction at one end, but in the opposite direction at the other end. Hold the coil still and move the screwdriver end into the coil, and the needle is moved in the same direction as when the coil was slipped over the same end. In this last experiment the galvanometer should be at least 3 ft. away, so the needle will not be affected magnetically by the motion of the screwdriver.

1111. *How can one tell the direction of the induced current?*

By common consent it is agreed to consider the lines of force as coming out from the north-seeking pole of a magnet and as going into the south pole. A convenient rule of thumb for determining the direction of induced E.M.F. or current is to hold the thumb and

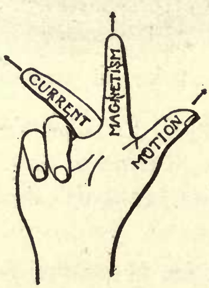


FIG. 1111.—RULE OF THUMB.

first and second fingers of the right hand at right angles to one another, as suggested in the figure. If the forefinger points in the

direction of the lines of force, the thumb in the direction of the motion, the central finger will point in the direction of the induced current.

1112. *How long does an induced current last?*

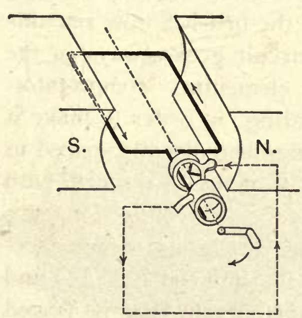
Only so long as the motion continues. The E.M.F. that causes the current is produced by the crossing or cutting of the lines of force, and is proportional to the rate of cutting.

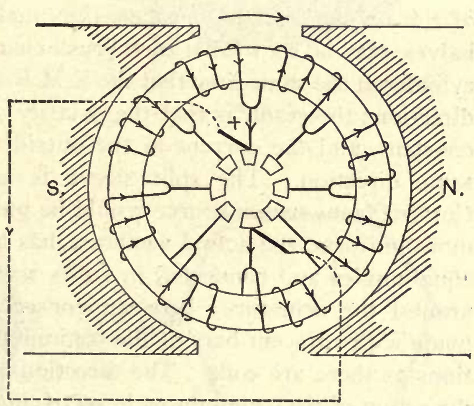
1113. *What determines the voltage or pressure of an induced current?*

The voltage equals the rate of cutting lines of force. It equals the product of the number of wires in the coil, the intensity of the magnetic field and the velocity of the motion. The E.M.F. is 1 volt when the product is 100,000,000 lines cut per second.

1114. *Is the current from a dynamo caused in any such way as described in No.* 1110?

The principle is the same, although it is developed in a different way. Instead of moving a coil back and forth, it is rotated between the poles of a magnet, as indicated in the figure. If the coil is rotated in the direction of the hands of a clock, the E.M.F. in the wire at the





FIGS. 1114A AND 1114B.—ELEMENTARY DYNAMOS.

left tends to send current toward the handle, while that in the other wire is in the opposite direction. When both wires are connected so as to form a closed circuit, current will flow around the circuit, as indicated by the arrows. After the loop has passed a position midway between the two poles, the wires begin to cross the magnetic lines in the opposite direction and the E.M.F. is reversed. The current in the loop, therefore, changes direction also. If the two wires

are connected only at one end, and the other ends are brought out and connected with an outside circuit, current will flow in it also. The current obtained from such a loop would not flow continuously in one direction, but would go first in one direction and then in the other, being known as an alternating current. By making the loop to consist of many turns of wire, the E.M.F. is increased proportionally. The alternating-current generators, as actually built, have a number of pairs of poles in the field magnets and a corresponding number of coils in the armature (see Nos. 1427, 1431, 1457); the coils are generally connected in series, so that their E.M.F's are added; the ends of the series of coils are connected to collecting rings, against which brushes make contact and so conduct the current to the outside circuit; in some alternators the field revolves and the armature is stationary, in which case no collecting rings or brushes are needed for the armature current (see Nos. 1460 and 1461). Dynamos for generating currents which always flow in the same direction, require development in a somewhat different way. If, instead of coming out to two collecting rings, the ends of the loop are connected with the halves of a split sleeve or cylinder, the brushes (see No. 1302) may be arranged so that one brush makes contact with one half the cylinder during half the revolution and with the other half during the rest of the revolution; the brushes, thus making contact with alternate halves, may be set so that each brush changes to the other half of the cylinder at the same time that the E.M.F. in the rotating loop changes direction; the result is that the polarity of the brushes now remains constant, and the current in the outside circuit goes always in the same direction. The split sleeve is an elementary commutator. Current from such a source would be pulsating; in order to make it more uniform, the actual armature has a number of coils spaced at equal angles and connected in series so as to make a complete path around the armature; between consecutive coils, connections are made with adjacent bars of the commutator, which has as many sections as there are coils. The direction of the induced E.M.F's and the action of the commutator in rectifying the current, may be traced in Fig. 1114B, which shows a diagram of an armature with eight coils.

1115. *What is the "field" of a dynamo?*

This word is used in three different senses: (A) It means the magnetism or the magnetic force in the space in which the wires move; in other words, the magnetic field in which the armature revolves. (B) The word sometimes refers to the iron through which the magnetic lines pass from one pole to the other. In many cases

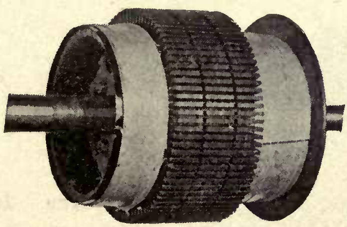
this also is the frame of the machine. (C) Sometimes men use the word, meaning the "field coil," the coil of wire which is placed around part of the iron frame, and which becomes the source of magnetic force when it carries current. The first is the correct use.

1116. *What is the armature?*

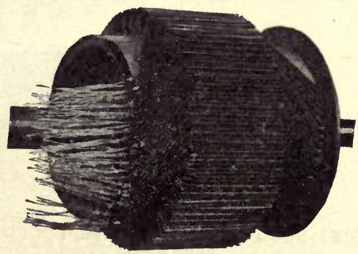
The armature is the part of the machine in which the E.M.F. is produced, or in which the current is generated. As a general rule, the armature revolves and the field is stationary, but in a few alternators the armature is stationary and the magnetic field revolves.

1117. *Of what parts is the armature composed?*

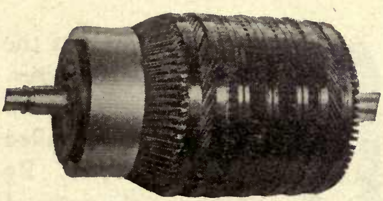
The armature wires or coils are the principal part. These are attached to the "armature core," which generally consists of a large



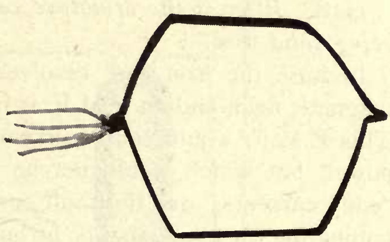
Armature core ready for the insertion of the coil.



Armature core with part of the coils in place.



Completed armature.



Form wound coil.

FIG. 1117.—ARMATURES.

number of discs of sheet iron fastened together upon a spider or directly upon the shaft. Another part is the "commutator," to which

the ends of the armature wires are attached and with which the "brushes" make contact to carry the current to the outside circuit. In large dynamos, the iron core does not extend to the shaft, but has the center cut away. In direct-current machines for high voltage, such as arc-light dynamos (see Figs. 1142 and 1162) where it is necessary to have considerable distances between coils which have a wide difference of potential, the armature winding usually consists of coils, each of which surrounds only one side of the iron core, as indicated in Fig. 1114B; such an armature is known as a Gramme ring, after its inventor. For circuits of 750 volts or less, armatures commonly have the coils fastened on the surface or in slots and so spaced that when one side of a coil is under one magnet pole, the opposite side is in a corresponding position under the next pole; these coils may be wound in jigs (see example in Fig. 1304), or they may be wound directly on the armature core, as in the accompanying fig-

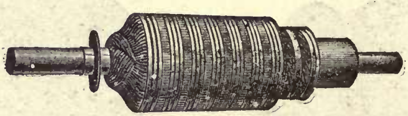


FIG. 1117B.—A DRUM ARMATURE.

ures; such armatures are called drum or Siemens armatures. In any armature, an important part is the insulation, which must be carefully selected and placed so as to prevent the possibility of electrical connection between the windings and the iron core. (See also Nos. 1300 to 1304 and 1427 to 1470 for motors and alternators.)

1118. *Why is the armature core made of thin sheets instead of being solid iron?*

Because the iron core revolves with the armature wires in the magnetic field, and an E.M.F. is induced in the iron as in the wires. This E.M.F. would cause currents in the iron which would absorb power, but which would not be useful. Such currents are called "eddy currents," or "Foucault currents," after their discoverer. By laminating the core—that is, by building it up of sheets—the paths of these currents are broken up and they are prevented.

1119. *Why is an iron core used for supporting the armature wires? Would not wood or some other insulating material do as well?*

Iron is used because it offers a good path for the magnetic field. The entire magnetic circuit of the dynamo or motor is made of soft iron so far as possible, because iron makes an easier path than air. By having the armature core made of iron, the total amount of mag-

netism is greater, and a much larger part of the total magnetism passes through the armature. All of the magnetism that does not pass through the armature is lost. (See Nos. 745 to 758). The

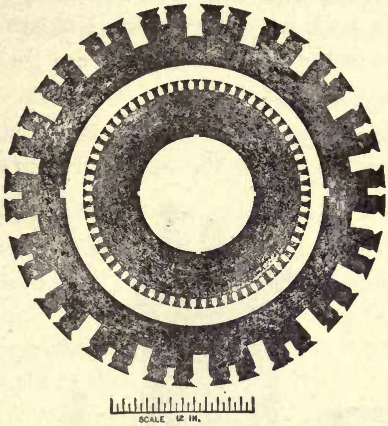


FIG. 1119A.—ARMATURE DISCS.

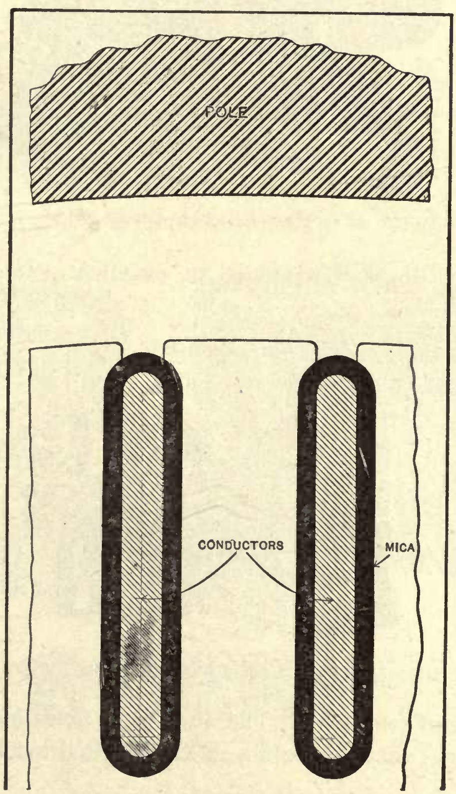


FIG. 1119B.—5000-HP ARMATURE.

armature core discs are sometimes smooth, and more often have notches or teeth. The teeth improve the magnetic circuit, and also support the armature windings. The cuts show a number of different designs of armature discs. The second figure shows a part of the armature of a 5000-hp generator at Niagara Falls, one of the largest generators in the world.

1120. *What is a bipolar machine?*

A bipolar machine is one whose field magnet has only two poles, one being a "north" pole and the other, of course, a "south" pole.

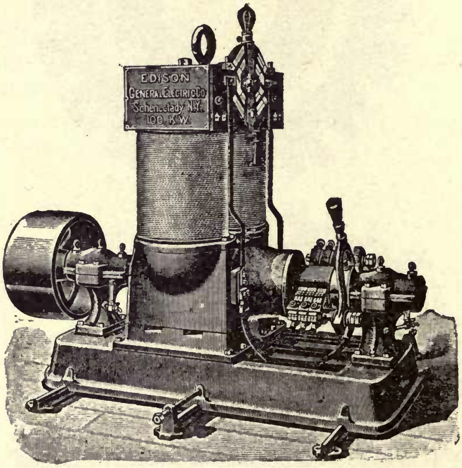


FIG. 1120.—EDISON DYNAMO.

The familiar Edison dynamo is an excellent example of such a machine.

1121. *What is a multipolar machine?*

A multipolar (abbreviated to "m.p." or "MP") machine has

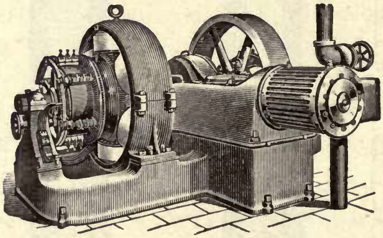


FIG. 1121.—MULTIPOLAR DIRECT-CURRENT DYNAMO.

some multiple of two poles. The number of poles increases with the size of machine, varying from 4 in small belted machines to as high

as 24 in 1600-kw. generators directly connected to steam engines. Alternators generally have more poles than direct-current machines of equal output. One company makes alternators with 6 poles for 30 kw. size, 56 poles for 3500 kw. size; one machine has 92 poles. Generally speaking, as the rated output of the machine increases, the number of revolutions per minute decreases and the number of poles increases, the peripheral speed being nearly constant.

1122. *Does a dynamo or motor always have an even number of poles?*

There are as many " north " poles as there are " south." The poles are sometimes divided, but the " north " and " south " are equal.

1123. *What is meant by a north pole of a dynamo or motor?*

It is the pole which attracts the south-seeking pole of a compass needle. The north pole of a bipolar machine is the one which would point toward the north if the machine was freely suspended or supported on bearings, so as to be free to rotate in any direction like a compass needle.

1124. *What is the source of the magnet field in dynamos?*

Some small machines use permanent magnets made of hardened steel. The machines used for furnishing light or power have electromagnets, the current in the field coils being taken from another machine, or from the same machine.

1125. *What are magneto machines?*

A magneto is a small dynamo whose field is furnished by a per-

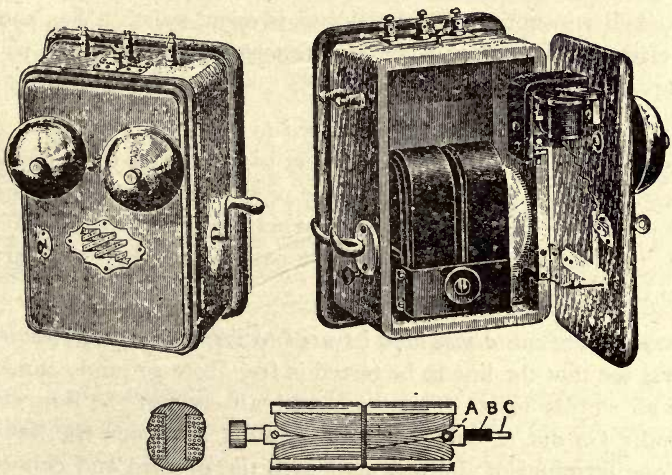


FIG. 1125.—MAGNETO.

manent magnet. A common form used for ringing telephone call bells, and for some kinds of testing, is illustrated in the figure. The steel magnets which give the field are seen in the lower part of the case. The crank at the side of the box is connected with a toothed wheel inside, which gears into a smaller wheel on the end of the armature, so that the armature makes several revolutions for one of the crank. The armature itself consists of a coil of wire wound lengthwise around an iron core, as shown in the lower figure. This is seen to be a development of the simple loop shown with No. 1114. A good magneto will develop 50 volts to 100 volts when the crank is turned rapidly. It delivers an alternating current.

1126. *How is a magneto used for testing?*

The generator and ringer are connected in series with the circuit to be tested. When the handle is turned, the bell will ring if the

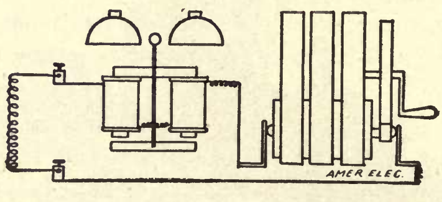


FIG. 1126.—MAGNETO TESTING BELL.

resistance of circuit is not too high, say 100,000 ohms, the loudness of the sound depending on speed and resistance.

1127. *How can a magneto be used to detect an open circuit?*

The bell will not ring if the circuit is open, unless it has considerable electrostatic capacity. The magneto should be tested to see if it rings when short-circuited on itself.

1128. *How can a magneto be used to detect a "ground"?*

Connect one terminal of the magnet to the circuit to be tested, and connect the other terminal to a water pipe or other good ground connection. If the line has electrical connection with the ground at any point, the bell will ring, its current passing through the earth between the two ground connections.

1129. *How can a magneto be used to locate an open circuit?*

First see that the line to be tested is free from ground connections, as in all similar tests. Then connect both ends of the line with the ground. Go out to some convenient point and open the line; connect one terminal of the magneto with the ground and connect the other, first with one side of the circuit and then with the other. If

the bell rings on either side it indicates that that side of circuit is continuous to the grounded terminal. If the bell will not ring on one side, it indicates that the break is on that side. The next step is to close the circuit again at the point tested and go to another point in the direction indicated and test again. By this process it is usually not difficult to locate a break.

1130. *Is the magneto always reliable?*

No. The field magnets get weak with age and the pivots of the bell hammer get out of order, so that an old magneto will not ring through so high a resistance as when new. Also a magneto will sometimes give false indications, by ringing when the circuit is open.

1131. *How can a magneto ring when the circuit is open?*

It is because the magneto gives an alternating E.M.F. Should a direct E.M.F. be applied to an open circuit, only a transient charging current would flow, which might or might not ring the bell.

1132. *How can a line have capacity?*

The two conductors of a circuit may be considered as the two plates or coatings of a condenser (see Nos. 111 to 117). These are charged and discharged twice each revolution of the magneto armature (see Nos. 1114 and 1401), current going first in one direction and then in the other, the strength of current varying with the E.M.F. of the magneto and with the capacity of the circuit.

1133. *Do electric circuits generally have capacity?*

Every circuit has more or less electrostatic capacity. On short aërial lines it is rarely important. Telephone cables are made with great care to reduce capacity to a minimum. On long distance lines, capacity becomes important. (See Nos. 115 and 1135.)

1134. *What determines the amount of capacity in a circuit?*

The capacity depends upon the size of the two surfaces, their distance apart, and the nature of the substance between them. It should be remembered that there is capacity not only between the outgoing and incoming wires of a circuit, but also between each wire and the earth. In the case of underground conductors, the capacity between two wires and between each one and the earth may be considerable.

1135. *Is the capacity of a circuit of any special importance?*

Capacity is generally unimportant on short lines for direct current at low potential difference; its effect is magnified by high voltages and high frequencies such as are common with lightning. Thus,

a condenser with plates the size of a silver dollar may vitiate the working of a jump-spark coil on a gas engine. With the ordinary alternating current frequencies of 25 or 60 cycles per second, the electrostatic capacity of long distance transmission lines limits the smallest amount of power that can be handled. For example, electrostatically charging the 65-mile line between Canyon Ferry and Butte, Mont., requires a current of about 14 amperes at 66,000 volts, involving over 2000 apparent horsepower independent of power delivered.

1136. *Is not the word "capacity" used with several different meanings?*

The word sometimes means electrostatic capacity, as just discussed; it sometimes refers to the amount of current a conductor will carry without unsafe heating, and it is also used with reference to the safe or greatest output of a machine. It is generally not difficult to tell which meaning is intended.

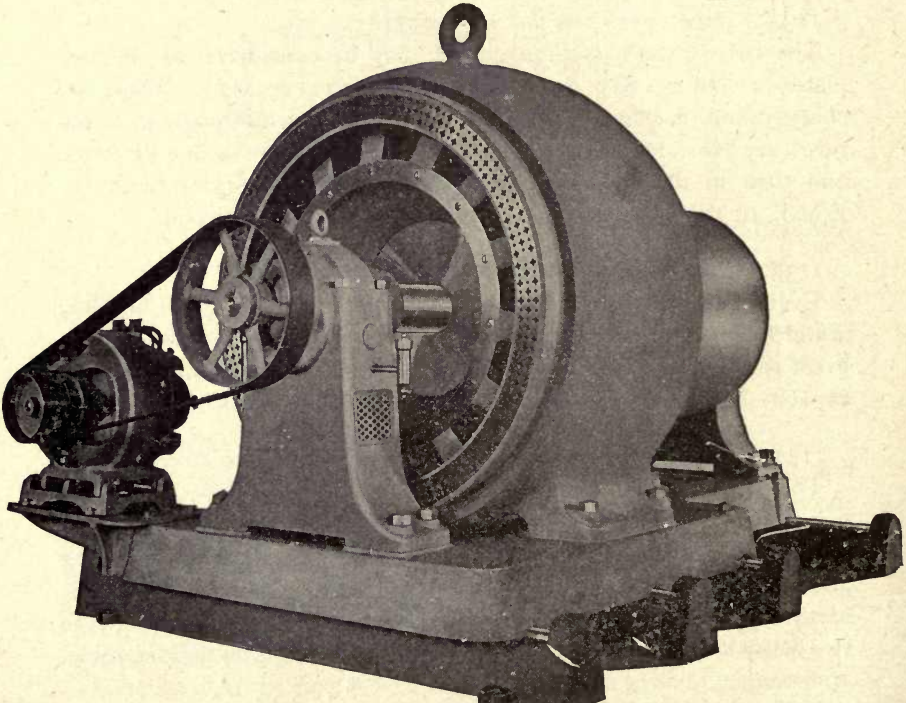


FIG. 1137.—ALTERNATOR WITH EXCITER.

1137. *What is a separately excited dynamo?*

It is one in which the current in the field magnet coils comes from another source than the machine itself.

1138. *What kind of dynamos are separately excited?*

It is common to use a small auxiliary dynamo called an exciter to furnish current for the field coils of alternators. Sometimes also large continuous current dynamos are separately excited, especially when used on a grounded circuit, as for electric railway work.

1139. *What classes of dynamos excite their own fields?*

These are sometimes called "self-excited" machines, and may have the field coils connected "in series," or "in shunt," or they may be "compound wound."

1140. *What is a series dynamo?*

A series dynamo is one in which the whole current from the armature passes through the field magnet coils, as suggested in the

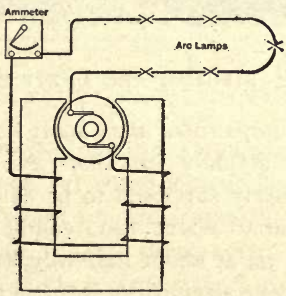


FIG. 1140.—SERIES DYNAMO.

figure. The field coils consist of comparatively coarse wire, usually about twice the size of the wire on the armature.

1141. *For what purposes are series dynamos used?*

Principally for arc lighting.

1142. *What sort of current is obtained from series dynamos?*

Continuous, constant current; that is, the current always goes in the same direction, and is of nearly constant strength. The current from a series dynamo actually does vary to some extent, unless the machine has a good regulator, being greater as the number of lamps or other resistance in the circuit becomes less.

1143. *How much current is given by series dynamos?*

Dynamos supplying "full arcs" of 2000 nominal c-p. of the "open" variety, are generally regulated for 9.6 amperes; when the arcs are enclosed, the current is set for 6.6 amperes. For "half arcs" of 1200 nominal c-p., the current is adjusted for 6.8 amperes when the arcs are open, or for 5 amperes when they are enclosed. (See Nos. 484 to 493.)

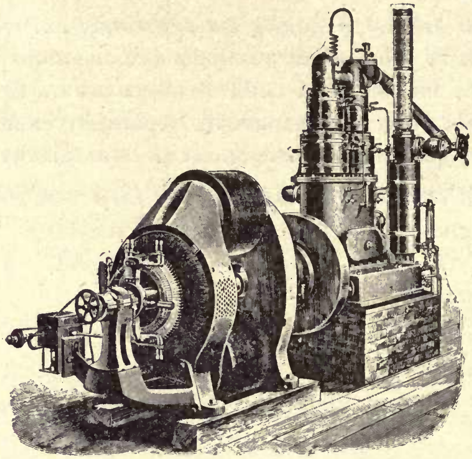


FIG. 1142.—BIPOLAR ARC LIGHT DYNAMO.

1144. *Why are arc lamps rated at so many nominal candle-power?*

Because the light is actually less than was once supposed. An arc light that was formerly supposed to be equal to 2000 candles is now known to be equal to about 1200 candles in the direction of greatest intensity; that is, at about half-way between the horizontal and vertical. The average strength of light in all directions is about 800 candles. Much trouble has been caused from the discrepancy between the actual and nominal candle-power, and it is more common to specify nominal c-p., or better, watts taken by lamps.

1145. *What is the voltage of series dynamos?*

In each dynamo this varies with the number of lamps, being higher as more lamps are in circuit. Each "open" arc lamp requires about 50 volts. "Enclosed" arc lamps usually require about 80 volts each. Arc-light dynamos are made in different sizes to operate from 10 to 220 lights.

1146. *What is a shunt dynamo?*

A shunt dynamo has the field magnets excited by means of a coil of many turns of comparatively fine wire. The field coil is connected to both terminals of the armature, so that a small part of the armature current goes through the field coil and the balance of the current goes through the outside circuit, as suggested in the figure. The field coil is thus a shunt or side circuit to the main circuit.

1147. *What sort of current is obtained from shunt dynamos?*

The voltage or pressure is approximately constant, but the current varies according to the number of lamps lighted. The voltage becomes less as the current increases, unless the machine is regulated.

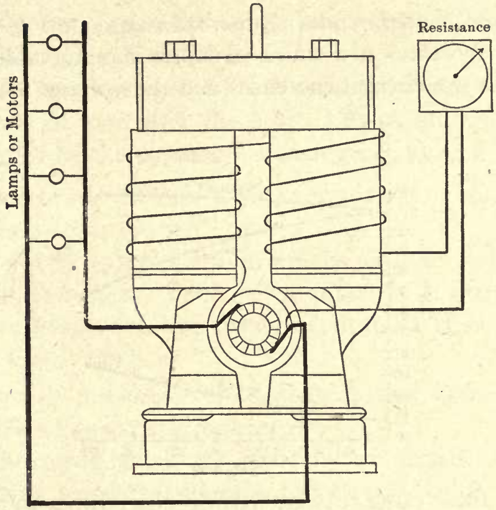


FIG. 1146.—SHUNT WOUND DYNAMO.

1148. *For what purposes are shunt dynamos used?*

For furnishing current for incandescent lamps, motors, heaters, and to an increasing extent, for arc lamps.

1149. *How is a shunt dynamo regulated?*

By means of an adjustable resistance in a resistance box or rheostat, connected in series with the field coil. By cutting out part of this resistance, more current goes through the field coil. This strengthens the magnet, and so increases the voltage of the dynamo. In a similar way the voltage is made lower by putting more resistance in the field circuit. The rheostat is generally adjusted by hand.

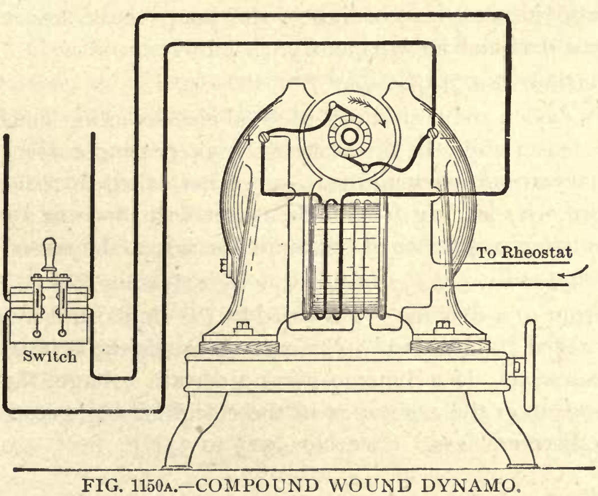


FIG. 1150A.—COMPOUND WOUND DYNAMO.

1150. *What are compound dynamos?*

Compound dynamos are shunt dynamos having additional series field coils. As the current increases and the voltage would decrease

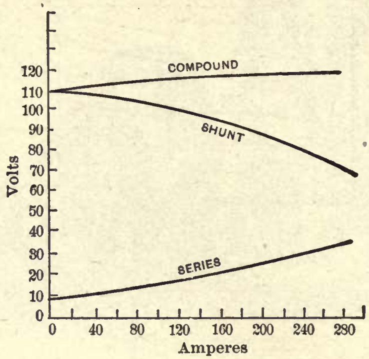


FIG. 1150B.—CHARACTERISTICS OF COMPOUND DYNAMO.

with a simple shunt machine, the current through the series coils strengthens the magnetic field, and so raises the voltage, or at least keeps it from falling. (See No. 1244.)

1151. *What is an over-compounded dynamo?*

A machine is said to be over-compounded when the series coils are so strong that the voltage becomes higher as the current increases. (See No. 1245.)

1152. *Why are machines over-compounded?*

In order to keep the voltage constant at some point at a distance from the dynamo. As the current on a line increases, the "drop," or volts lost on a line, increases proportionally. Unless the voltage at the dynamo increases accordingly, the lamps have lower voltage and become dull and unsatisfactory.

1153. *What is a "teaser coil"?*

In early days a compound coil used on electroplating machine was called the teaser coil. In the monocyclic alternating-current system, the auxiliary armature winding is sometimes called the teaser winding, the line wire leading from it the teaser wire, and the voltage between the latter and either of the main line wires, the teaser voltage.

1154. *What fixes the current given by a dynamo?*

The output of a dynamo is governed by the simple and well-known principle called "Ohm's law"—the current equals the voltage divided by the resistance. If a dynamo gives a certain voltage, the current will depend upon the resistance in the circuit, being greater as the resistance becomes less. (See Nos. 315 to 334.)

1155. *Does the resistance of an arc-lighting circuit increase when more lamps are turned on?*

Yes. All the lamps are generally in series, so that the same current passes through all, one after the other. From 40 volts to 60 volts must be supplied by the dynamo for each arc lamp in a series circuit.

1156. *How is the current kept constant when more lamps are connected into a series circuit?*

If the current is to remain constant the voltage must increase as the resistance increases. Each lamp added in a series circuit increases the resistance of the circuit, and so increases the voltage necessary at the dynamo.

1157. *Does the resistance of an incandescent lighting circuit increase when more lamps are connected?*

No. Incandescent lamps are generally connected in multiple between the mains, somewhat like the rounds of a ladder. Each lamp gets its own current almost independently of the others, as each gas jet or water faucet is independent. The larger the number of lamps connected in multiple the greater is the current; just as the more gas jets are open, the more gas is burned. If the lamps are all of the same candle-power, their resistances are about equal, and the combined resistance of all the lamps is practically the resistance of one divided by the number of lamps.

1158. *Is there any general principle by which all dynamos are regulated to give constant current or constant voltage?*

All dynamos, whether for arc or incandescent lighting, and whether giving continuous or alternating currents, regulate by adjusting the voltage. Constant-current dynamos must have the voltage increase or decrease accordingly as the resistance of the circuit changes. Constant-potential dynamos generally require some regulation to keep the voltage constant, because there is a tendency for the voltage to fall as the current increases.

1159. *What governs the voltage of a dynamo?*

The voltage equals the rate of cutting magnetic lines of force; that is, the product of the number of r. p. m., the number of conductors on the armature and the number of magnetic lines of force through the armature (see Nos. 1113 and 1114). The voltage may be varied by changing any one of the three factors.

1160. *Are dynamos ever regulated by changing the speed of the armature?*

The engine governor is sometimes changed so as to run faster with large load. This is not suitable for alternating current

generators operating in multiple or supplying a motor load, but will do for direct current machines. A common case is in the use of the ordinary magneto. The voltage depends on the speed of the armature, and the faster the handle is turned the higher the voltage. By turning the handle faster, the bell will ring through a higher resistance. (See Nos. 1125 and 1126). This method of regulation is not generally suitable for dynamos. Frequently the voltage is affected by changes of speed that are not desired, as often happens when dynamos are driven from the same power as other machines whose load is changing.

1161. *Is it possible to regulate voltage by changing the number of conductors while a machine is running?*

A number of arc dynamos regulate in practically this way. Some use two brushes on each side and spread the brushes, thus short-circuiting some of the sections of the armature. In the Thomson-Houston arc machines the whole armature is short-circuited six times every revolution for a longer or shorter period varying with the position of the brushes.

1162. *Do not some machines regulate the voltage by shifting the brushes?*

Yes. An ordinary constant-potential dynamo, such as used for incandescent lighting, is affected to a considerable extent by the position of the brushes.

The Western Electric arc dynamo (Fig. 1142) is regulated entirely by shifting the brushes, which are placed so as to touch the commutator bars connected with armature sections directly under the pole pieces, so that some of the wires are inducing E.M.F in the opposite direction to the rest. Shifting the position of the brushes changes the number of wires working against the main E.M.F. This changes the effective number of wires on the armature and also affects the distortion of the magnetic field by the armature current. This method was used with Standard, Sperry and Edison arc dynamos. The Fort Wayne (Wood) arc machine regulates by shifting and spreading the brushes. The Excelsior and the new Brush arc dynamos shift the brushes and also change the strength of the field magnet.

1163. *Are many dynamos regulated by changing the number of magnetic lines of force through the armature?*

Yes. All constant-potential or incandescent-lighting dynamos, and some constant-current or arc-lighting dynamos regulate by this method.

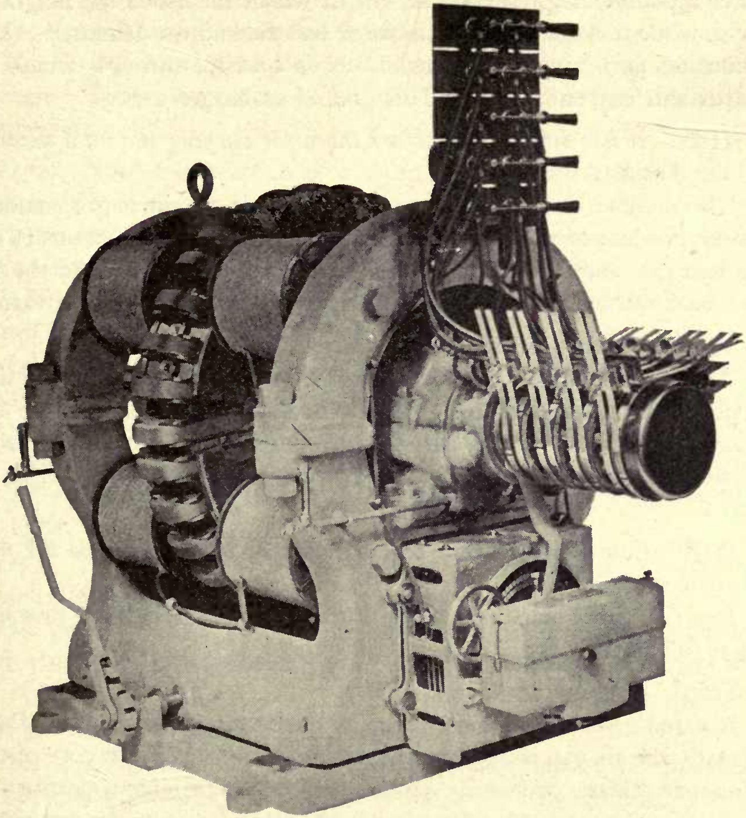


FIG. 1162.—BRUSH ARC GENERATOR FOR FOUR CIRCUITS.

1164. *What different ways are there for changing the number of magnetic lines of force through the armature?*

Either the total number of magnetic lines (the total amount of magnetism) may be changed, or the useful proportion of the total number may be changed.

1165. *How can the useful proportion of the whole amount of magnetism be changed?*

By providing another path beside the armature. (See Nos. 1119, 747, 756 and 757). Some small machines have a movable soft iron bar that may be placed so as to deflect more or less of the magnetism and conduct it from one pole to the other without passing through the armature. This is an unusual method and used only for small medical machines.

Another plan once used in an English arc lighting machine was to

have a double magnetic circuit, one of which furnished the magnetic field, while the other shunted more or less around the armature. The shunting part was surrounded by coils of wire through which an adjustable current passed. This plan is no longer used.

1166. *What different ways are there for varying the total amount of magnetism?*

The number of lines of force in a magnetic circuit is proportional to the product of the number of turns of wire by the amount of current in the magnetizing coil and is inversely proportional to the reluctance of the magnetic circuit. Any one of the three may be varied.

1167. *What is meant by reluctance?*

The reluctance of a magnetic circuit corresponds with the resistance of an electric circuit. The reluctance is proportional to the length of the circuit; it is inversely proportional to the area of cross section and also to the permeability of the circuit. (See Nos. 724 to 726.)

1168. *Can the reluctance of a dynamo be changed while the machine is running?*

In a few small machines, parts of the iron field circuit are movable so as to lengthen or shorten the "air gap."

1169. *What is the air gap?*

A name given to the part of the magnetic circuit composed of air. Usually the air gap is between the pole pieces and the iron core of the armature. More or less air gap is necessary to provide room for the armature wires and also for mechanical clearance between armature and pole pieces.

1170. *How can the amount of current in the magnetizing coil be varied?*

In shunt-wound machines this may be varied by changing the resistance in the rheostat. (See No. 1149). With series-wound machines (No. 1140) an adjustable resistance is sometimes shunted around the series field coil so that the field may be weakened by allowing more or less current to pass around the coil. The Brush arc dynamo regulates in this way. By reducing the resistance in the shunt, less current goes through the field coils so that the magnetic field becomes weaker, and consequently the E.M.F. of the armature is reduced.

1171. *How is a shunt dynamo started?*

If the machine has been running before and everything is in good order, simply let down the brushes so that they press against the com-

mutator, and bring the machine up to speed. If everything is all right, the field magnetism will "pick up" as the machine comes up to speed, and in a short time the machine will be generating full voltage. The voltage may be adjusted up or down by moving the rheostat handle.

1172. *How does the field of a shunt dynamo pick up?*

After a machine is stopped, the iron of the field magnet retains more or less magnetism, being, in fact, a semi-permanent magnet. This residual magnetism furnishes a weak field which causes a small E.M.F. to be induced in the wires on the armature as the machine comes up to speed. If the armature and field coils form part of a closed circuit, the small E.M.F. induced by the residual magnetism sends a small current through the circuit. This current strengthens the magnetic field and causes a still higher E.M.F. to be induced. This again sends still more current through the field coils, and the machine thus quickly builds up its magnetism and voltage to full strength.

1173. *What prevents the voltage of a shunt dynamo from increasing indefinitely?*

The machine is so designed that the iron of the field magnet becomes more or less saturated by the time the voltage has risen to the desired amount.

1174. *What is meant by the saturation of iron?*

This may be explained by the accompanying figure, in which the curved line represents the relation between the magnetizing current and the resulting magnetization. After the iron has been magnetized once it retains a certain amount, as indicated by the curve, beginning

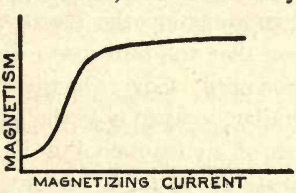


FIG. 1174.—SATURATION CURVE.

at some distance above zero. For small magnetizing forces the permeability of the iron is small, and the magnetization increases slowly. The permeability then increases and the magnetization increases rapidly until the iron approaches the saturation limit. The upper sharp bend in the curve is called the saturation point, since after the iron has been magnetized up to this point, it is difficult to magnetize it much more strongly. (See also No. 763.)

1175. *How can one tell the normal speed of a dynamo?*

Usually the speed is stamped on the name plate on the machine or on the end of the armature shaft. Belt-driven machines usually have a velocity of 3000 ft. per minute as measured around the outside of the armature, although some machines run at 4000 ft. or more. Machines directly coupled to engines sometimes run as slowly as 1600 ft. per minute.

1176. *How can one tell the normal voltage of a shunt dynamo?*

A shunt dynamo usually has quite a wide range of voltages, at which it will operate successfully. It is common to have a machine able to generate about 50 per cent above normal voltage when the main switch is open so that the machine delivers no current except for its own fields, when the resistance is all cut out of the shunt field rheostat and when the machine is running at full speed. It is now customary to make shunt dynamos for 125, 250 and 600 volts.

1177. *How can one tell the full load current of a shunt dynamo?*

If this is not marked upon the name plate or armature shaft, one can tell either by running the machine for one or two hours or by finding the size of the wire on the armature. Modern dynamos are so designed that the temperature of the armature will not rise more than 50 deg. cent. above the temperature of the room after giving full-load current for 6 to 18 hours.

1178. *How can one determine the temperature of an armature?*

Have a thermometer that reads as high as 212 degs. F., or 100 degs. C., preferably a straight one without a wooden or tin case, and with the scale marked on the glass tube. Immediately after the machine has stopped running lay the thermometer upon the armature in such a position that the bulb rests directly upon the armature wires or on the iron core. Cover the thermometer carefully with waste or something similar, so as to hold the bulb in position, and also to prevent any currents of air from cooling it. In a few minutes the thermometer will indicate the temperature of the armature. The difference between this and the reading of a similar thermometer hung in the air a few feet from the machine gives the rise of temperature of the armature. Temperature rise in machine windings is preferably determined by the increase in resistance. (See No. 340.)

1179. *Is it true that an armature is cooler while running than after it stops?*

It is true with armatures that are not thoroughly ventilated, because while running the armature creates a current of air like a

fan that carries off the heat from the surface, so that the surface is cooler than the inside of the armature. When the armature stops, the current of air also stops, and the whole of the armature comes to about the same temperature. Therefore, the surface becomes warmer for some time after the armature stops running.

1180. *How can one tell the allowable current from the size of the armature wire?*

Determine the size of the wire and the total number of circuits among which the armature current is divided. Determine also whether each path consists of a single wire or of two or more wound as one. From a wire table, find the number of "circular mils" in the wire used, multiply by the total number of wires in parallel, and divide by 600. The result is about the number of amperes the armature can probably deliver without excessive heating.

1181. *Why divide by* 600?

Because experience shows that 600 circ. mils per amp. is about the smallest size of wire allowable. This figure varies in different cases from 325 to 650.

1182. *How can one tell the number of paths for the current in an armature?*

In a two-pole machine the current divides into two equal parts, each side carrying half. In multipolar machines having an even number of commutator segments, the number of paths in the armature is the same as the number of poles in the field. If the number of commutator segments is an odd number, such as 95 or 101, the armature has a two-path winding. Alternator armatures have either a single or double path, the double path being indicated where the leads to the collecting rings come from opposite sides of the armature.

1183. *In starting a shunt dynamo, should the main line switch be closed before the machine is up to voltage or after?*

If the machine is working on the same circuits with other machines, or with a storage battery, it is, of course, necessary to make the voltage of the machine equal to that on the line before connecting it in. If the machine works alone, the switch may be closed either before or after the voltage comes up. The load is thrown on suddenly if the switch is closed after the machine is up, thus causing a strain on the belt, and possibly drawing water over into the engine cylinder. On the other hand, if the switch is closed before the voltage of the machine has come up, the load is picked up gradually, but the machine may be slow or may even refuse to pick up at all.

1184. *Why does a shunt machine pick up more slowly if the main switch is closed first?*

Because the resistance of the main line is so much less than that of the field that the small initial E.M.F. due to the residual magnetism, causes a much larger current in the armature than in the shunt field. If this is too large, the cross and back magnetizing force of the armature weakens the field more than the initial field current strengthens it, and so the machine can not build up.

1185. *If a shunt dynamo will not pick up, what is likely to be the trouble?*

The speed may be too low; the resistance of the external circuit may be too small; the brushes may not be in the proper position; some of the electrical connections in the dynamo may be loose, broken or improperly made; the field may have lost its residual magnetism.

1186. *How can one tell if the speed is too low?*

The proper speed is usually stamped on the name plate of the machine, or on one end of the armature shaft. If not marked on the

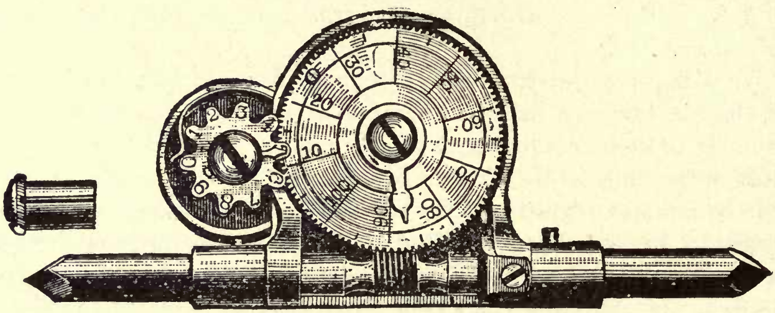


FIG. 1186A.—REVOLUTION COUNTER.

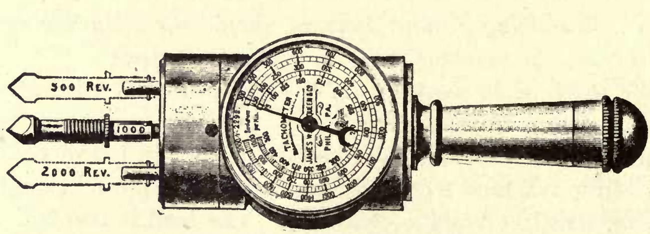


FIG. 1186B.—TACHOMETER.

machine, it may be found in the catalogue of the manufacturer. Otherwise it may be estimated as indicated in No. 1175. The actual speed of the armature may be measured by a revolution counter and watch, or by a tachometer, the sharp end of the spindle of the instru-

ment being held against the end of the armature shaft so that the two revolve at the same speed. Sometimes a convenient way is to count the engine speed by one's fingers, and then get the dynamo speed by multiplying the engine speed by the ratio of diameters of engine and dynamo pulleys.

1187. *How can the speed of an engine be counted if one has no speed indicator?*

If the engine does not run faster than about 100 r. p. m., one can count the number of strokes in a minute by keeping one eye on a watch, while the other watches the cross-head or piston rod. Sometimes one can stand so that the cross-head or valve stem will touch the hand at each stroke. When an engine runs too fast for one to count, he can get the speed by the use of the fingers of both hands, as follows: Keep a watch where its second hand can be seen at the same time as the valve rod or piston rod; by a little practice one can get the fingers of the right hand moving so that one finger comes down for each stroke of the engine; one finger of the left hand is brought down for each five or ten of the first; in this way each finger of the left hand represents five revolutions, and going over the whole left hand represents twenty-five revolutions; by bending one finger each time the left hand is covered, one may keep track of twenty-fives, and so can keep count of 125 revolutions. Some prefer to keep tally on the vest buttons. By this method it may be necessary to count the revolutions in a half or quarter minute and then multiply by two or four. By practice one can determine the speed of an engine or shaft running as high as 300 r. p. m.

1188. *How can one tell whether the brushes are in the proper positions?*

If there is little or no sparking when the machine is working, it is safe to conclude the brushes are set properly. On bi-polar machines the brushes should bear upon the commutator at points diametrically opposite; in general, the brushes should be so spaced as to divide the commutator into as many equal parts as there are poles in the field magnet. Most shunt dynamos, except Edison machines, should have the brushes touch the commutator at points opposite the space between the pole pieces, as indicated in Fig. 1150a. Care should be taken that the brushes make good electrical contact with the commutator. Sometimes the armature has so much end play that the brushes make poor contact, a temporary remedy for this being to hold a stick against one end of the armature so as to stop end play until the machine has picked up. Care should be taken also

that the springs press the brushes firmly, but flexibly, against the commutator.

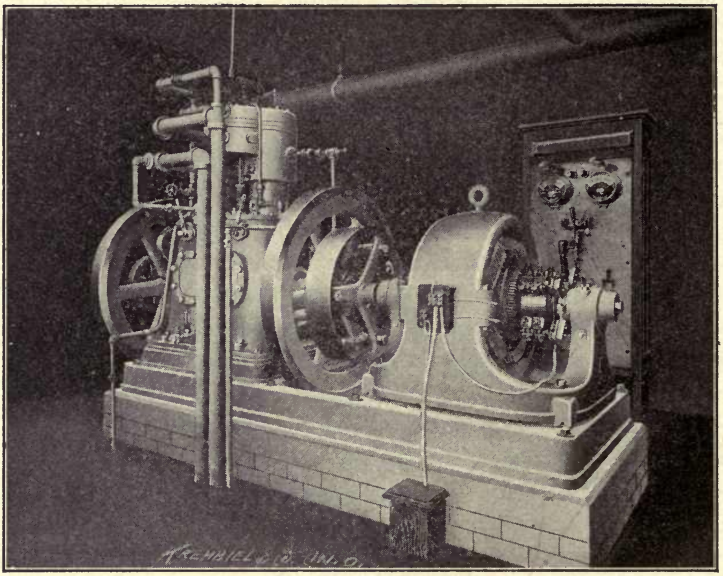


FIG. 1189.—MULTIPOLAR DYNAMO (DRIVEN BY GAS ENGINE).

1189. *Why are the brushes of a four-pole dynamo placed* 90 *degs. apart, instead of* 180?

Because of the arrangement of the winding. There are two distinct generating circuits in a four-pole machine, one corresponding to one pair of adjacent poles, and the other to the other pair; as in the case of a bipolar machine, the position of the brushes for each circuit is between the poles, which brings the brushes 90 degs. apart. Instead, however, of using four brushes, the two circuits are sometimes connected in parallel, thus reducing the brushes to two, although it is common to use four brushes to reduce the necessary length of commutator.

1190. *How are the brushes of a dynamo located?*

On some machines, the brushes are placed so as to bear on commutator bars almost opposite the middle of the polepieces. On others they are almost opposite a point midway between the poles. The position depends on the relative position of the commutator connections with reference to the windings, and is governed by convenience of connections or of access to the brushes (see No. 1120).

1191. *Should the brushes of a dynamo be in the same position with a large load as with a small load?*

Some machines are so designed that no shifting of the brushes is necessary. Usually the brushes must be moved forward, in the direction the armature rotates, as the load becomes larger. This is to reduce the sparking.

1192. *Of what materials are dynamo brushes made?*

They are made of copper sheets, copper wire gauze, combinations of copper and high-resistance metal, and are often made of carbon.

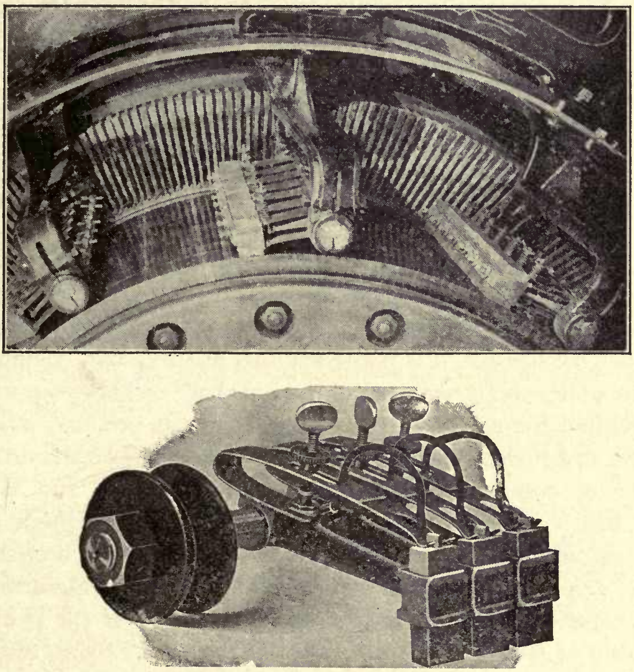


FIG. 1192A.—BRUSH-HOLDERS WITH CARBON BRUSHES.

Strip copper was used almost exclusively for many years. Carbon is generally used with large dynamos, especially when delivering current at more than 200 volts. Copper has the highest conductivity and carries the current to and from the armature with the least loss. When an armature is delivering a considerable current there is apt to be more or less sparking at the brushes on account of armature reactions. The brush should have high conductivity lengthwise, but low conductivity crosswise, the latter being found to reduce the sparking. If the total voltage is high, a little loss at the brushes does not make much difference, and high-resistance brushes of carbon are suitable for such machines. For low-voltage machines, such

as generators for 125 volts or less, the loss in the brushes may become a considerable percentage of the whole, so that other brushes are preferable. The tendency for sparking is reduced considerably by putting sheets of poor conductor, such as thin paper between the copper sheets. In the Wirt brushes, the central part is of copper, while the outer sheets are of high-resistance metal, which cuts down the sparking.

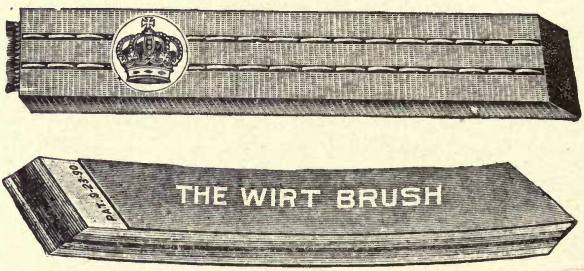


FIG. 1192B.—METALLIC BRUSHES.

1193. *What causes sparking at the brushes?*

Sparking occurs whenever there is a difference of potential between the brush and the part of the commutator that is passing out from under the brush. It is necessary that at times two commutator bars come under the brush, and so the armature coil between them is short-circuited for an instant. If the machine is properly designed and made, and if the brushes are properly placed, there should be no difference of potential between the commutator bar just coming under a brush and the bar just leaving it. This condition is not always met, and there is apt to be more or less voltage between the two bars, due to the magnetic action of the current in the armature. Such voltage will send a current across the face of the brush independently of the main current, and the reason for using the high-resistance carbon or other brush is to reduce this cross current, and therefore reduce the cutting of the commutator and brushes.

1194. *How can one tell if the resistance of the external circuit is too low?*

The machine will build up its voltage if the main current is open, as indicated in the figure; but will not build up if the main line is closed. The reasons are given in Nos. 1183 and 1184.

1195. *What electrical connections in the shunt dynamo are liable to become loose or broken?*

The connecting screws at binding posts and elsewhere are liable

to jar loose, and should, therefore, be tried about once a week with a screwdriver or wrench. The terminals of the fine wire of the shunt field coils of some machines are liable to be easily broken. Sometimes the connections between the armature wires and commutator become loose or broken. A frequent source of trouble is poor contact between the arm and segments of the regulating rheostat; this can be tested while the machine is running, but not working, by touching the ends of a short wire to the terminals leading to the rheostat so as to short-circuit it for a moment; if the trouble is in the rheostat, the machine will come up to voltage quickly when the rheostat is thus cut out. Sometimes the ends of the brushes get coated over with oil and dirt so as to make poor contact. In some machines oil is liable to get into the brush holder and connections, and so increase the resistance of the contact between the different parts. Trouble is less likely to occur from poor contacts if the machine is kept clean and all connections tight.

1196. *How are improper connections liable to occur in a dynamo?*

When the machine is first set up or after repairs, the connections between the armature and the fields are liable to get reversed; the field coils may be connected so as to oppose rather than assist each other; the machine may be short-circuited. Short-circuits are also liable to occur by accident or carelessness after the machine has been running all right.

1197. *How can one tell whether the different parts of a dynamo are properly connected?*

The simplest way is to compare the connections with the direction sheet and diagrams sent with the machine by the maker. If these are lacking, examine the machine and see whether it is series, shunt or compound-wound. Then connect the field coils in series or in shunt with the outside circuit as the case may be.

1198. *How can one tell whether a machine is series, shunt or compound?*

The name plate on the machine often tells. When it gives both the volts and amperes, the machine is for constant potential and is either shunt or compound-wound. When the name plate gives simply the current, as 6.8 or 9.6 or 10 amps., the machine is intended for constant current, and the field coil is to be connected in series with the armature. Another method is to examine the size of wire on the armature and field. If the field wire is larger than, or the same size as, the armature wire, the field and armature are intended to carry the same current and should be connected in series, as indicated in

No. 1140. If the field wire is much smaller than the armature wire, the field is intended to carry only part of the whole current, and it

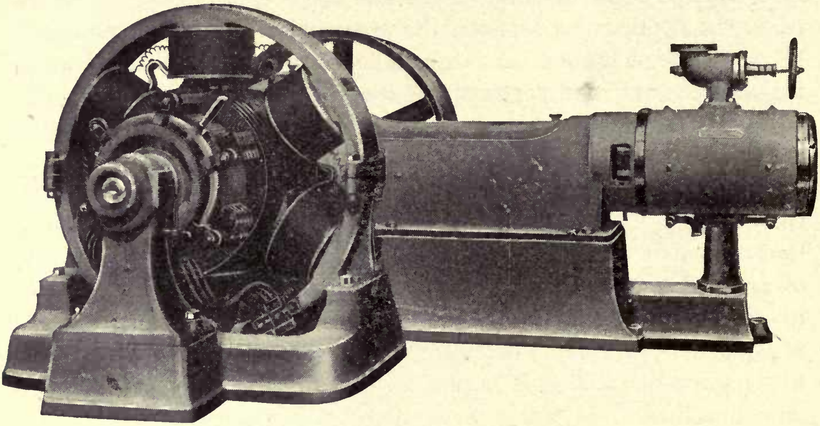


FIG. 1198.—COMPOUND DYNAMO.

should be connected in shunt with the main circuit, as indicated in No. 1146.

1199. *How can one tell whether the connections between the armature and field coils are reversed?*

If the machine picks up all right when brought up to full speed, the connections are proper. If it does not pick up, the field coils may be wrongly connected. This may be tested by a voltmeter connected across the armature terminals, as indicated in Fig. 1146, or by a compass needle placed a short distance from one of the pole pieces of the dynamo, in such a position that it no longer points to the north. If the machine is up to speed when the circuit through the field coils is open, the voltmeter will indicate a few volts due to the residual magnetism of the iron field frame, as explained in No. 1172. If the field coils are properly connected, this initial voltage will send current through the field coils in such a direction as to strengthen them and to cause a higher voltage in the armature. On the other hand, if the field coils are improperly connected, the current due to the initial voltage weakens the field magnetism and so prevents the machine from building up. This will be indicated by the initial voltage becoming less when the field circuit is closed; also by the needle of the compass being less strongly attracted.

1200. *When a dynamo has several field coils, should the coils be connected in series or in parallel?*

The different coils are almost always connected in series with one another so that the same current passes through each coil. The exceptions to this rule are that the series coils of a compound dynamo are connected in series with the main circuit, and the shunt coils carry only part, or none, of the current passing through the series coils. Again, in some large compound-wound dynamos, the different sections of the series field coils are connected in parallel, or may be connected either in parallel or in series.

1201. *What will happen if some of the field coils are reversed?*

If half of the coils oppose the other half, the machine will not pick up at all. If one of four or more coils is opposed to the others, the machine may pick up, but the voltage will be low and some of the brushes will spark badly.

1202. *How can one tell which coil is reversed?*

There should be an equal number of "north" and "south" poles in the field. This may be tested by a pocket compass. If there are more poles of one kind than the other, it indicates that some of the coils are reversed. In nearly all machines the poles should be alternately north and south. An exception to this rule was the Sperry arc machine, which had two north poles together and two south poles together.

1203. *In connecting up a dynamo for the first time, how can one be sure to connect the different coils in the right direction?*

If there is no direction sheet or diagram, or if the terminals of the different coils are not made so as to indicate the method of connection, get a few cells of battery and a pocket compass. See if the residual magnetism in the poles is alternately north and south. Send a small current from the battery through one of the coils and note which end of the coil must be connected to the zinc or negative terminal of the battery in order to strengthen the residual magnetism. Mark with a string or bit of paper the negative end of each coil as thus found. Connect the marked end of one coil to the unmarked end of its neighbor, continuing thus until only two ends are left as the terminals of the entire series. These are then to be connected with the armature, as indicated in No. 1199.

1204. *How can one tell by a compass needle whether a magnet pole is getting stronger or weaker?*

Place the needle near enough to the pole so that it is deflected considerably from pointing north and south. With the compass remaining in the same place, the needle will be deflected further from the north and south line as the magnet pole becomes stronger, approaching a limit when the needle points east and west. If the needle is disturbed, so as to vibrate from side to side, it will be found that the needle vibrates faster as the magnet pole gets stronger, or as the needle comes closer to the pole.

1205. *How may a dynamo lose its residual magnetism?*

By rough handling or by long standing unused, the magnetism becomes weakened. Sometimes the armature reaction due to a heavy short-circuit will demagnetize or even reverse the field magnet. Sometimes, also, the induction current due to lightning will demagnetize or reverse the field.

1206. *How may the field magnetism become reversed?*

By lightning or short-circuit, as mentioned above in No. 1205. This is liable to occur also when charging batteries, especially if the dynamo is compound wound (see Nos. 1150 and 1244). Dynamos when not working sometimes become reversed by the stray magnetic field of other dynamos near by.

1207. *When the residual magnetism is lost, how can one make a dynamo pick up?*

The field may be temporarily magnetized by current from another dynamo. Even a few cells of battery will sometimes send enough current through the field coils to set up sufficient initial magnetism to allow the machine to build up. (Of course the battery circuit should be broken before the machine comes up to full voltage). Sometimes one end of a bar magnet held against one of the pole pieces will magnetize the field enough for a start.

1208. *Will a dynamo pick up if the residual magnetism is reversed?*

Yes. The initial voltage is reversed, the initial current through the field coils is reversed and the machine builds up with its voltage reversed. The current delivered by the machine is, of course, reversed, and trouble will occur if one attempts to connect the dynamo in multiple with other machines not reversed. If the machine is sup-

plying arc lamps, they will be reversed also and will throw their light upward instead of downward. (See Nos. 484 and 485.)

1209. *What remedy should be applied when a dynamo becomes reversed?*

Reverse the residual magnetism by current from another machine or from a battery. If this is not convenient, the connections between the machine and the line may be transposed or crossed, so that what was formerly the positive terminal of the dynamo, but is now the negative terminal, will be connected with the negative line terminal and *vice versa.*

1210. *Can not the dynamo be reversed by reversing the connections between the armature and field?*

No, for then the machine could not build up. (See No. 1199.)

1211. *Will a dynamo pick up if the armature rotates in the opposite direction?*

No. Because by reversing the direction of rotation, the voltage due to the residual magnetic field (see No. 1172) is reversed and sends a current through the field coils in the wrong direction, so that the dynamo can not build up.

1212. *What changes must be made if it is necessary to run a dynamo armature in the opposite direction from what was intended?*

The connections between the armature and the field terminals must be reversed so that the initial current will go through the field coils in the right direction (see Nos. 1199 and 1211.)

1213. *What is to be done if the brushes suddenly begin to flash or spark excessively?*

Look first at the ammeter or current indicator to see if the machine is delivering too much current. Then see if the brushes make good contact, since the springs or brush holders sometimes get loose. Then see if the commutator has a high bar, a low bar or an open circuit.

1214. *What can be done if the dynamo is overloaded?*

If the current is more than 50 per cent or 100 per cent above the rated capacity of the dynamo, and if it continues more than a few minutes, the main switch should be opened. If the machine is supplying lights whose sudden extinction might cause a panic and endanger human life, one should risk injury to the dynamo rather than to life. When it is unsafe to shut down, the dynamo may be relieved by changing the regulator so as to lower the voltage until the lamps give only a dim light. The current will decrease with the voltage. Modern machines will carry 50 per cent overload two hours safely.

1215. *How can one avoid an excess of current?*

All parts of the circuit should be protected by safety fuses of suitable capacity so that any branch taking too much current will be cut off automatically by the melting of the fuses. Dynamos are commonly protected by circuit breakers. (See Nos. 421 to 440.)

1216. *If a plant has no ammeter or current indicator, how can the attendant tell when a dynamo is delivering too much current?*

In a well made modern dynamo, no part should get too hot to be touched by the hand after the dynamo is shut down. If the armature begins to smoke, or if it smells strongly of shellac, it is carrying an unsafe current. So long as the armature does not get uncomfortably hot during the regular run, the load is within safe limits. With some experience one can get an idea of the temperature of the armature by feeling the hot air coming from the armature.

1217. *Can two arc dynamos be coupled together so as to work in series on the same circuit?*

This is frequently done. The two machies are connected in series so that the same current passes through each and the voltage of one

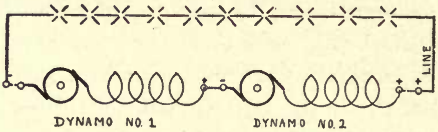


FIG. 1217.—TWO ARC DYNAMOS IN SERIES.

is added to that of the other. Connect the positive terminal of No. 1 to negative terminal of No. 2; connect the positive line terminal to positive terminal of No. 2; connect the negative line terminal to negative terminal of No. 1, as indicated in the figure.

1218. *What advantages are there in coupling two arc dynamos in series?*

Coupling two machines in series gives a higher voltage, and so allows more arc lamps to be connected on one circuit. By thus using one long circuit instead of two or more shorter ones, considerable wire is saved in returning to the station, and so less electrical energy is lost on the line. Again, the circuits may become so loaded that they are not even loads for the dynamos, and some machines would carry less than full load while others would have an overload. By connecting several circuits and several dynamos in one circuit, it is often possible to arrange that each dynamo works at full load.

1219. *Is it true that two arc dynamos of equal size connected in series can operate more than twice as many lamps than one alone?*

This is sometimes found to be true. It is probably due to the fact that in a long circuit with many lamps, the fluctuations due to the feeding of the lamps become more uniform as a smaller proportion are feeding at the same time. This allows the dynamos to work with less margin for fluctuation.

1220. *Is it not dangerous to connect several arc machines in series?*

It is to some extent. Of course, the voltage is higher and it is necessary to have the lines, lamps and machines well insulated. The liability to getting a serious or fatal shock is increased, but no one has any business handling an arc circuit, unless he uses proper precautions, and to most people it would make little difference whether the shock was from 2000 volts or 10,000 volts.

1221. *How are the machines started when two are coupled in series?*

Make all the connections and then bring both machines up to speed gradually and together. Or, if this is not convenient or desirable, move the brushes or regulator of each machine to the position of no load and then throw in both machines at once.

1222. *How are two or more incandescent dynamos coupled for combined output?*

The two machines are generally connected in parallel or in multiple

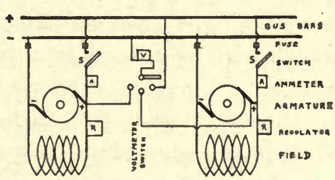


FIG. 1222.—COUPLING CONSTANT POTENTIAL DYNAMOS.

on the same mains, as indicated in the figure. Both machines are regulated to give practically the same voltage and current.

1223. *When two incandescent dynamos are to supply the same mains, how may the two be started safely?*

This depends upon the load. If it comes on all at once, both machines should be started at the same time. Connect both machines to the circuit and bring both up to speeed gradually. Watch the

ammeters and adjust the regulators so that both machines may pick up at the same rate, and each take its proper share of the load. If the load comes on gradually, so that one machine can carry it all for some time, another method is used.

1224. *What are bus-bars?*

Bus-bars are large conductors to which a number of machines may be connected, 'bus being an abbreviation of the Latin word "omnibus," meaning "for all." In large stations the bus-bars are commonly built up of a number of flat strips.

1225. *How can an incandescent dynamo be safely coupled in parallel with another one already working?*

Bring the second machine up to speed and adjust it until it gives the same voltage as the one already working and then close the switch so as to connect the two machines in parallel. A convenient way to do this is to have a voltmeter with a switch having three or more points as shown in Fig. 1222. One side of the voltmeter is connected permanently to one of the mains, to which also one side of each dynamo is connected. Suppose the machine at the left is already connected to the mains and is at work, its main switch, *S*, being, of course, closed. Move the voltmeter switch so as to measure the voltage of the line, or, what is the same thing, the voltage of the machine at work. Then throw the switch over to measure the voltage on the fresh machine. Adjust the rheostat or regulator of the fresh machine until its voltage is just the same or a trifle higher than that on the other machine. When the voltage of the fresh machine is just right, close its switch, *S*. This should cause no disturbance whatever, and the switch may be opened or closed without any flash or fluctuation of voltage. After the switch is closed, the regulator of the fresh machine should be moved so as to make it pick up its share of the load, while at the same time the regulator of the warm machine should be moved in the opposite direction so as throw off some of the load to the fresh machine.

1226. *How can one tell whether each machine is taking its proper share of the load?*

Each machine should have its own ammeter (sometimes called ampere-meter or current indicator) which will show at all times the current being supplied. If the machines are all of the same size, the attendant should so adjust the rheostats and brushes that each machine may give the same current.

1227. *Is it practicable or desirable to couple a small dynamo in parallel with a large one?*

There is no difficulty at all in doing this, except to see that the smaller machine does not get more than its full share of the load.

1228. *Are not incandescent dynamos sometimes coupled by means of double-pole switches instead of single-pole switches, as indicated in Fig.* 1222?

Shunt dynamos commonly have a double-pole switch, and compound dynamos have a three-pole (or a double and a single) switch, so that they are entirely isolated when not working. (See No. 1251.)

1229. *Are not galvanometers sometimes used instead of voltmeters for indicating when a dynamo is ready to be thrown into circuit?*

Formerly a switch was arranged so that a galvanometer might be connected between the two sides of the single-pole switch between the dynamo and the main. The galvanometer needle will then be thrown to one side if the voltage of the fresh dynamo is too low, and to the other side if it is too high. When the voltage is just right, the galvanometer needle will not be deflected. This is now obsolete.

1230. *What will happen if the switch is closed before the fresh machine is quite up to the voltage on the line?*

The fresh machine will take current from the line, running as a motor and increasing the load on the other dynamo. This may not do anything worse than cause the voltage on the line to drop to some extent, but it is not a good thing to do.

1231. *When a dynamo runs as a motor, does it not run backward, revolving in the opposite direction?*

Not if it is an incandescent dynamo. Arc dynamos are usually series wound, that is, with the field coil in series with the line; and a series motor runs in the opposite direction from a series dynamo. But incandescent machines are usually shunt machines or sometimes compound wound. A shunt machine runs in the same direction whether as a dynamo or as a motor. A compound machine would run in the same direction as a motor unless the current were very heavy, when it might stop and then start in the opposite direction.

1232. *If two machines are working in parallel on the same circuit so that both give the same voltage, how is it possible to regulate the division of load between them?*

This results from the fact that the voltage at the terminals of the dynamo is somewhat smaller than the total voltage induced in the

armature wires. There is unavoidably more or less resistance in the armature wires, commutator, brushes and connections, so that the current suffers some loss of voltage before reaching the external circuit, the loss of voltage being equal to the product of the current by the resistance. When two machines are coupled in parallel, the voltage at the terminals must be the same for both. If the total voltage of either machine is increased, the current delivered by it increases until the lost voltage again equals the difference between the total and that on the line. When two machines are working together in parallel, if the total voltage of one is increased while the other is not changed, the voltage on the external circuit is raised slightly, so that the difference between the total and external voltage of the other machine becomes less. The result is that the first machine takes more of the load and the other less. (See also No. 1242.)

1233. *How may the voltage of a shunt machine be regulated?*

This is usually done by adjusting the rheostat, which is a variable resistance connected with the circuit of the shunt field magnet coil, as shown in Fig. 1222. As resistance is cut out of the rheostat, more current passes through the field magnet coil and increases the amount of magnetism, which correspondingly increases the total voltage induced in the armature. Another method which can be used to a limited extent with most incandescent dynamos is to move the brushes slightly forward or backward, so long as they do not spark.

1234. *How can one machine be thrown out of circuit when the load drops off so that the load can be handled by the remaining machine?*

Move the rheostats and brushes of both machines so as to shift the load from one machine to the other without disturbing the voltage on the mains, as explained in No. 1232. When all the current is off from one machine, its switch may be opened and the machine may then be stopped.

1235. *How can both machines be shut down at once if the load does not go off so that one machine can handle it?*

If both dynamos are driven by the same engine, the simplest way is to shut off steam slowly and let both dynamos and engine die together. If this is not practicable, move both rheostats around gradually to the position of lowest voltage, watching both ammeters, and being careful that the voltage drops equally on both, and then open both main switches at the same time.

1236. *What will happen if one attempts to couple two dynamos, one of which has become reversed?*

This will make a bad short-circuit and will melt the fuses on both machines, besides burning the brushes and commutators badly. It is also liable to strip the armature wires out of place and to break the belts or throw them off.

1237. *How can one tell whether a dynamo is reversed or not?*

The voltmeter will usually show it. If the voltmeter is not one of the variety with a permanent magnet, it will not indicate polarity. If the voltmeter is connected as shown in Fig. 1222, it will indicate double voltage when connected to the dynamo which is reversed.

1238. *How can one correct a dynamo that is reversed?*

Lift the brushes and then close the main switch, so that current from the mains will flow through the magnet coil and magnetize the field properly. Then move the rheostat to the position of lowest voltage so as to reduce the current through the fields; open the switch slowly; then place the brushes in position and let the machine build up. This method may also be applied to a new dynamo that will not build up. If current can not be taken from mains, a few cells of battery will usually supply enough current.

1239. *Why should the field switch be opened slowly after magnetizing a dynamo?*

This to avoid danger to the insulation of the field coils on account of the high voltage induced in them. When the current ceases to flow through the field coils, the machine begins to lose its magnetism, and the number of magnetic lines of force through the field coils diminishes correspondingly. This induces an E.M.F. in the coils in such a direction as to tend to keep up the magnetizing current. The induced E.M.F. is proportional to the number of turns of wire in the coils, and also to the rapidity with which the magnetic field changes strength. It follows then that when the current through a shunt field coil of many turns of wire is cut off suddenly, an E.M.F. is caused that may be several times higher than the ordinary working voltage, and so may cause a spark to jump through the insulation, and thus make connection between the coil and the frame of the machine, or short-circuit part of the coil. By putting in all the resistance of the rheostat and then opening the switch slowly, the current dies out gradually and the induced E.M.F. becomes comparatively harmless.

1240. *Why does the voltage of a shunt dynamo fall off after it has been working for some time?*

This is because the machine gradually becomes warm by use. The resistance of the wire in the field and armature windings increases about four-tenths of 1 per cent for each deg. C. rise of temperature, or 1 per cent for every 5 degs. of the F. scale. Therefore, as the dynamo warms up by working, the resistance of the shunt field coils increases and less current passes through them. This weakens the magnetic field and so lowers the voltage of the dynamo. In order to keep up the voltage of the dynamo, it is therefore necessary to cut out some resistance from the rheostat in order to balance the increasing resistance of the field coil.

1241. *Why does a dynamo get warm by working?*

It is impossible to entirely avoid friction at the bearings and between the brushes and commutator. There is also some unavoidable loss by what is known as "hysteresis" or magnetic friction, as the magnetization of the armature is reversed twice for each revolution. A further source of loss comes from the fact that the wire used in the dynamo has more or less resistance which opposes the current somewhat as friction opposes motion. The work done in sending current through resistance, the work in overcoming the friction of the bearings and brushes, and that in overcoming hysteresis and eddy current losses in the armature, all this is changed into heat, which raises the temperature of the machine. (See No. 415.)

1242. *Why does the voltage of a shunt machine drop off when the load is increased?*

This comes from several causes. There is liable to be more or less slipping of the belt as the load increases, thus reducing the speed of rotation of the armature and consequently lowering the voltage. There is also more or less resistance in the machine, part of it being in the wire, and therefore unavoidable, and part being due to imperfect contact between the brushes and commutator and at other joints in the circuit. Even if the total voltage induced in the armature were not affected by change of load, the resistance in the circuit causes a drop of voltage equal to the product of current by resistance, or the product of amperes and ohms. The voltage between the terminals of the shunt circuit therefore becomes less than the total voltage in the armature, and consequently less current goes through the shunt field coils. This weakens the magnetizing force and in turn lessens the total voltage. Again, the current in the armature coils has a magnetizing effect that weakens and distorts

the magnetization from the field coils. This " armature reaction " is proportional to the armature current and helps lower the voltage as the load increases. (See also Nos. 1232 and 1258.)

1243. *How can the voltage of a shunt dynamo be kept up as the load increases?*

It is customary to have an adjustable resistance (called a rheostat) in series with the shunt field coils, as indicated in Fig. 1146. Resistance may then be cut out by moving the rheostat handle as desired. The voltage may also be kept constant automatically by compounding the dynamo.

1244. *What is a compound-wound dynamo?*

A compound-wound dynamo has two sets of field coils. (See Nos. 1150 and 1151). As indicated in Fig. 1146, the shunt coil consists of a large number of turns of comparatively fine wire and is connected to the armature terminals or to the machine terminals, so as to form a shunt to the external circuit. The shunt coil carries a small fraction of the total current and usually furnishes the larger part of the magnetizing force. A compound dynamo has also a series coil of comparatively few turns of large wire, which is connected between the armature and the external circuit. The current through the series coil is practically the same as that in the armature and in the external circuit. The magnetizing effect of the series coil is in the same direction as that of the shunt coil and strengthens the magnetization as the load increases. The series coil may be adjusted so as to keep the voltage of the machine constant, or it may raise the voltage as the load increases. In the latter case, the machine is said to be "over-compounded."

1245. *What is an inter-pole machine?*

An inter-pole machine has series wound auxiliary poles between the main poles, for the purpose of balancing the armature cross-magnetizing force, thus improving the commutation and reducing the sparking. Similar poles on motors allow wide variation of field strength for the purpose of changing the speed. (See Nos. 1193 and 1380.)

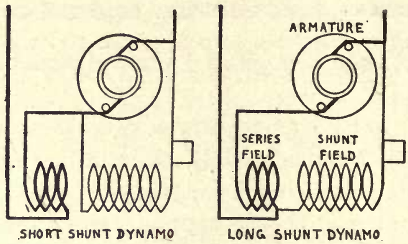
1246. *What is meant by "short-shunt" compound dynamos?*

In short-shunt dynamos, one terminal of the shunt field coil is connected between the armature and the series coil, as indicated in the figure.

1247. *What is meant by "long-shunt" compound dynamos?*

In long-shunt dynamos, the terminals of the shunt field coil are

connected to the outside terminals of the machine, as indicated in the figure.



FIGS. 1246 AND 1247.—COMPOUND WOUND DYNAMOS.

1248 *What are the relative advantages of long-shunt and short-shunt dynamos?*

Practically there is very little difference between them, since the drop in voltage through the series coil is very small. If the machine is to give constant voltage at its terminals or at the bus-bars at the switchboard, it is somewhat simpler to calculate the number of turns of wire necessary for the series coil if the shunt coil is connected with the terminals and so gets a constant current. Again, when several machines are operated in multiple, if they are connected long-shunt, the shunt field coils may be connected directly to the bus-bars at the switchboard, and so the field of one machine may be magnetized by those already running. This enables one to get a machine ready for service more quickly than when it must pick up by itself. It also insures that the polarity of the fresh machine is not reversed.

1249. *How are compound dynamos coupled to work in multiple?*

Compound machines act very much like shunt machines, and, in general, the explanations in Nos. 1222 to 1235 hold good for compound machines. With compound machines it is necessary to have an extra bus-bar or equalizer making a common connection for all the machines between the series coils and the armatures, as indicated in Fig. 1251.

1250. *Why is the equalizer necessary with compound machines?*

It is to help divide the load more evenly among the different machines. If the machines were coupled directly in parallel, the current from each armature would go through its own series field coil. Thus it might happen that when the load was increased, if one machine was a little more sensitive than the others, it would take more than its fair share of the load; this extra current through its series coil would strengthen its field and cause it to generate still more and

more current until its belt would slip or its fuse would blow and open the circuit. The load would thus fail to divide equally and the operator would have to adjust the rheostats and brushes. Another reason for using the equalizer is that, if a dynamo should be thrown into circuit when its voltage was lower than that of the other machines, or if for any reason it should afterward become lower, it would take current from the line; this current passing through the series field coils in the wrong direction would weaken the field and so reduce the voltage of that machine still further; the result would be that the low machine would run as a motor and take more and more current from the other machines.

1251. *How does the equalizer help balance the load?*

By coupling all of the machines to the equalizer so that all have a common connection between the armature and the series coils, the currents from all the armatures unite and then divide among the different series coils. By this means, if one armature tends to deliver

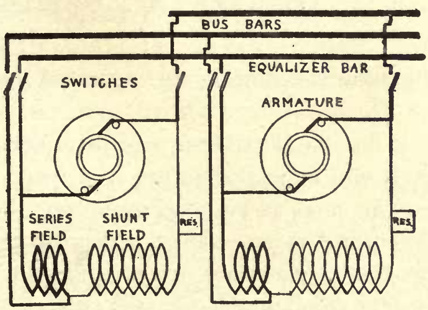


FIG. 1251.—COMPOUND MACHINES WITH EQUALIZER.

more than its proportion of the whole current, it strengthens the current in the series coils of all the machines, and not its own alone. On the other hand, if one machine tends to shirk its load, some of the current from the other machines goes through its series coil and strengthens its field so that it delivers more current.

1252. *How large conductors should be used for the equalizer?*

Strictly the equalizer bar or bus should have no resistance, but since it is impossible to avoid all resistance, this should be as small as practicable. Sometimes the equalizer connections for all the dynamos are run to a common point, so that there is no equalizer bus. The rule for determining the sizes of the equalizer connections is to make the resistance from the equalizer bar through the series field coil to the bus-bar such that each series coil shall carry the same

share of the load that its armature should carry. In practice, it is frequently necessary to connect an adjustable resistance in parallel or in series with the series coil.

1253. *Does it make any difference whether the equalizer is on the positive or negative side of compound-wound machines?*

It makes no difference which side of the machine the equalizer is connected to except that, of course, it must be connected to the same side the series field is joined to. Many railroad companies connect the series field and equalizer on the negative side of the machines, so as to give a low voltage between equalizer bus and ground.

1254. *Is it necessary to have the equalizer on the negative side of the machines in order to connect them with storage batteries?*

In connection with storage batteries, it is only necessary to connect the battery between the equalizer and the opposite bus, rather than between the outside bus-bars, so that in case the dynamo slows down and the storage battery discharges back through it, the current will not pass through the series field and reverse the magnetization of the machine.

1255. *Can compound machines be operated in multiple with shunt machines? If so, how?*

Not as a rule. It may be possible to run them for a short time on a steady load, but it will be in the nature of a feat. The voltage of the compound machine rises as the load comes on; the voltage of the shunt machine falls, and this tends to make the former drive the latter as a motor, unless rheostats are closely watched. The best way is to cut out the compound coils and run all the machines as simple shunt dynamos. If the compound machine is "under-compounded" (so that its voltage does not rise as the load increases), the compound and shunt machines will work together safely, but the shunt machine will take less than its proper share of the load.

1256. *Do the above directions apply to alternating current generators?*

They apply to a limited extent to alternators, especially those having the exciter directly connected, or having a commutator for compounding the field. They are treated more fully in No. 1427, etc.

1257. *Does the position of the brushes have anything to do with the successful balancing of the load among several dynamos?*

Very much. If the field coils and equalizer connections are adjusted for satisfactory division of the load, with the brushes of all the machines set exactly alike, it is found that shifting the brushes

of any machine makes it take more or less than its share. The closer the brushes are to the neutral position, the more current the machine will deliver.

1258. *Why does the position of the brushes affect the sensitiveness of dynamos?*

With nearly all dynamos it is necessary to move the brushes forward, that is, in the direction of rotation, when the load increases. This is because the current flowing in the armature coils exerts a magnetizing influence which distorts and weakens the magnetic field due to the field coils. On account of this distortion, it is necessary to move the brushes forward, so as to get them on or near the new neutral or non-sparking position. But the forward lead given to the brushes also increases the weakening magnetic effect of the armature current. It follows that if several similar machines are working in multiple, an equal increase of current in all the armatures would weaken the field of those having greater forward lead more than those with less lead of brushes. Consequently, the machine with more brush lead and weakened field would take a smaller proportion of the whole load than the one with little lead. (See No. 1232.) In large stations it is important to give the same lead to the brushes of all the machines, so as not to throw all the load on a few in case of short-circuit or other sudden load.

1259. *What is the trouble when one or two machines of a set refuse to take their share of the load?*

It may be too great resistance in the series field magnet coil or in the equalizer connections, so that the magnetic field is not properly strengthened as the load increases. (See Nos. 1244, 1250 and 1252.) Too much lead of brushes has the same effect as just explained (see No. 1258); a dirty commutator, loose or dirty connections in the brush holder or cables, loose connection between armature and commutator, will have the same effect by increasing the resistance of the armature circuit. (See No. 1232.) Such trouble may also be caused by slipping of the belt, if too loose or if oily and slippery. This cause would be indicated when the dynamo took its proper share of load until the load became heavy, after which it would take less than its share, or would take the same load regardless of the total load.

1260. *What is a booster?*

When speaking of continuous currents, a booster is a comparatively small dynamo connected into a circuit to increase the voltage from some other source. The field is sometimes magnetized by

coils in series with the armature, and sometimes the machine is excited from another source. A booster is generally driven by a motor, the two armatures being directly coupled, although boosters are sometimes driven from the engine or line shaft. (See also No. 1472.)

1261. *For what is a booster used?*

It is used to raise the voltage of one or more circuits higher than that on the rest of the system. When a number of feeders run out from the station, the longest ones and those carrying the heaviest loads are apt to have so much drop on the line that the pressure at the lamps or motors at the further end becomes undesirably low. It would not do to raise the voltage on all the lines to suit those that were low, so the economical remedy is to raise the voltage on those that have too great drop. Boosters are also used in connection with storage battery plants for the purpose of raising the voltage of the bus-bars to the amount necessary for charging the batteries. If the battery can be charged at a time when the distributing circuits can be cut off, or can be handled by another dynamo, the batteries may be charged directly from a dynamo without a booster by simply raising the voltage of that dynamo.

1262. *What are auxiliary bus-bars?*

In order to avoid the necessity for boosters, some stations have an extra bus-bar, which is kept at a higher pressure than the main bus, and to this are connected the feeders that have an extra large drop.

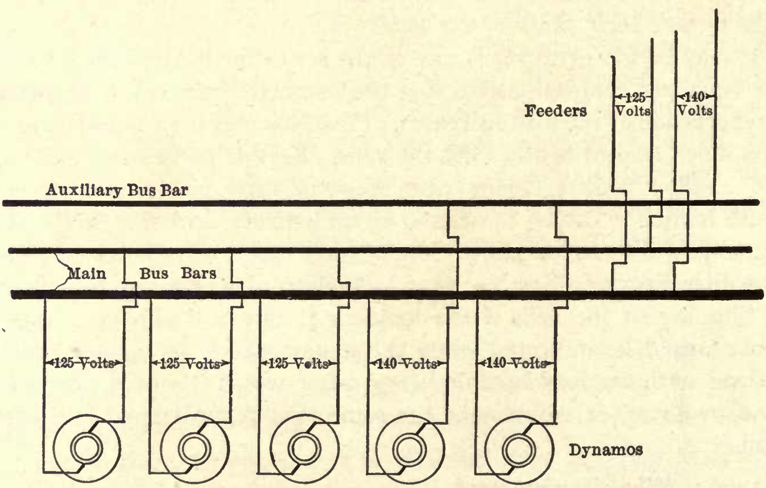


FIG. 1262.—MAIN AND AUXILIARY BUS-BARS.

One or more dynamos maintain the pressure between the auxiliary bus and the common negative bus. The figure shows the arrangement.

1263. *Does a booster generate current in raising a voltage?*

In a sense, it does. The current flowing in the booster circuit equals the total E.M.F. (the sum of that from the main dynamo plus that due to the booster, allowing for the C.E.M.F. of any motors on the line), divided by the total resistance in the line. If one so prefers, he may say, therefore, that part of the current comes from the booster, although it must be remembered that the whole current passes not only through the booster, but also through the dynamo. Strictly speaking, a dynamo does not generate current; it sets up an E.M.F. which causes current to pass.

1264. *What is a motor-generator?*

A motor-generator is a transforming device consisting of a motor mechanically connected to one or more generators. Either motor or generator may be made for direct current or for alternating current of any reasonable voltage or frequency. Two alternating current machines may be motor-generators or frequency changers.

1265. *What is a dynamotor?*

A dynamotor combines both motor and generator action in one magnetic field with two armatures or with two windings on one armature.

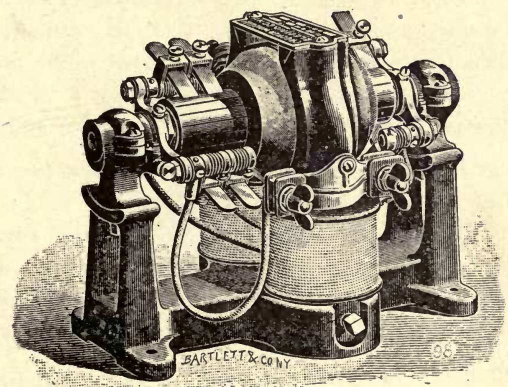


FIG. 1265.—DYNAMOTOR.

1266. *For what purposes are dynamotors used?*

Numbers of dynamotors are used in large telegraph offices for supplying currents at various voltages. One armature winding is designed for the 110-volt lighting circuit, while the other winding is suited to deliver current at one of the various voltages desired. Dynamotors are sometimes used to obtain current for incan-

descent lighting at 110 volts from a power circuit at 500 volts. Other machines are used for obtaining heavy current at low voltage, such as is required for electroplating or electrotyping, current for the motor end being taken from the regular circuit at 110 volts or 500 volts. Others are designed for charging automobile batteries.

1267. *Is there not a great loss in changing the voltage by a dynamotor?*

Not so much as one might at first think. In a moderately small machine, say of 10-kw capacity, the efficiency of the motor part will be about 90 per cent, and that of the dynamo end about the same. The combined efficiency of the combination will be the product, or 81 per cent. For example, if 10,000 watts be supplied at the motor, about 8100 watts may be obtained at the dynamo end.

1268. *When a dynamotor is used to reduce the voltage, is it possible to obtain a larger current from the dynamo end than is supplied at the motor end?*

Yes. It is possible to take out a larger current than is supplied. This is possible because the larger current is at lower voltage than the current supplied. The power is the product of current by voltage, and these two might have any values so long as their product was less than that of the current and voltage supplied at the motor end. For example, suppose the motor takes 20 amps. at 500 volts; the power taken is $20 \times 500 = 10{,}000$ watts. The generator end might deliver 73.6 amps. at 110 volts, making a product of 8100 watts, or 81 per cent of that furnished at the motor end.

1269. *What becomes of the difference between the* 10,000 *watts supplied and the* 8100 *watts delivered?*

It is used up by unavoidable losses in the machine, such as friction at the bearings and brushes, heating in the armature wires due to their resistance, the current necessary for exciting the magnetic field, and heating of the armature core due to hysteresis and eddy currents in the iron.

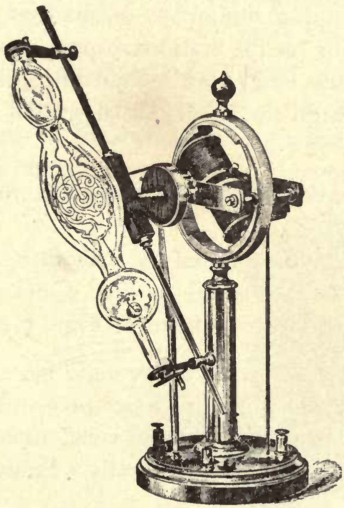
CHAPTER XI.

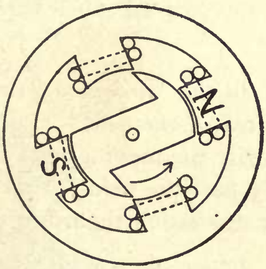
MOTORS.

(Direct Current.)

1300. *What kind of motor is the easiest to understand?*

Perhaps the simplest is the "oblique approach" motors for toys or small sizes only, such as shown in Fig. 1300*a*. These must usually be started by hand. The moving and stationary parts are both magnetized by the same coil, and are so designed that the path of the

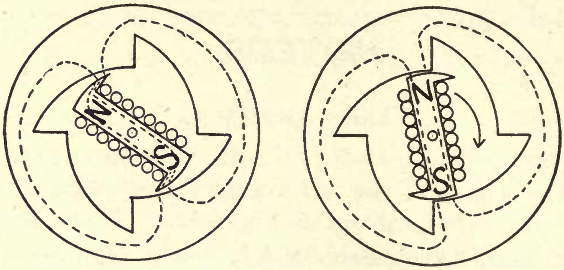




FIGS. 1300A AND 1300D.—OBLIQUE APPROACH MOTORS.

magnetic lines of force becomes shorter and shorter as the armature revolves until it reaches the shortest path, when the current is cut off for a short time and the attraction ceases until the momentum has carried the armature past. Figs. *b* and *c* illustrate the principle involved. Suppose that the armature is in the position shown in Fig. *b*, when current is sent through the coil around the pivoted piece, N-S. The current sets up magnetic lines which extend through the iron circuit somewhat in the direction shown by the dotted lines. The tendency of these lines to shorten draws the movable piece around to the position shown in Fig. *c*. It would stop here, because in this position the air gap is shorter than in any other position; but a commu-

tator is arranged so that the current is cut off at this point and the moving piece keeps on moving by its own momentum, until it reaches a position one-quarter turn ahead of the position shown in Fig. *b*,



FIGS. 1300B AND 1300C.—OBLIQUE APPROACH MOTOR.

when current is again sent through a similar set of changes. Some motors of this type have the coils on the stationary part, which has usually more than one pair of coils and poles, the current going first through one pair and then through the other, as suggested in Fig. 1300D.

1301. *In the "oblique approach" motors, which part is the armature and which the field?*

Ordinarily the moving part would be called the armature, and the stationary part the field. This is easy to see in Fig. *d*, but there is room for discussion regarding the motor shown in Figs. *b* and *c*.

1302. *What class of motors is easiest to understand next?*

Those in which the moving part has two or more projecting ends like those on the armatures of the "oblique approach" motors, but whose field magnet and armature have separate coils. Examples of

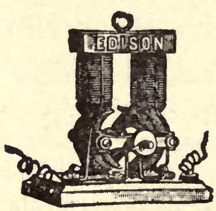


FIG. 1302.—TOY MOTOR.

these are shown in the accompanying figures. The simpler one is the "Edison" toy motor, whose field is a sort of horseshoe magnet, and whose armature is the shape of the capital letter I or H. The two ends of the coil upon the armature are connected respectively to the

halves of a split sleeve, which is carried upon the shaft and upon which two stationary brushes rub; it is evident that if these brushes are set properly, one brush will press against one part of the sleeve for one-half a revolution of the armature, and upon the other part of the sleeve during the remainder of the revolution. If current is sent through the motor when the armature is in the position shown in the figure, the magnetic lines of force will pass through the circuit and in shortening will draw the armature to the horizontal position; now, if the brushes have been arranged properly, the commutator will have turned around far enough so that each brush presses against a different bar and the current goes through the armature in the opposite direction; the armature and field now repel instead of attract, and when the momentum has carried the armature past the dead center it will be attracted in the other direction, and so the rotation will continue.

1303. *How does the "Porter" motor operate?*

This motor, which is shown in the figure, has three poles in its armature. The commutator likewise is in three sections. The brushes are placed diametrically opposite, so that they press against

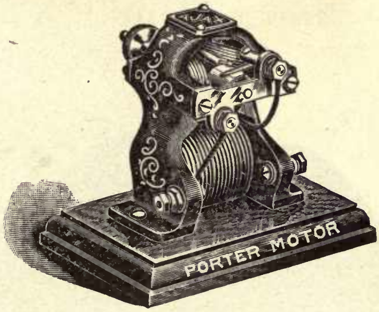


FIG. 1303.—PORTER MOTOR.

only two of the segments most of the time. Current is sent through the two poles which are in the position to pull the hardest, and when one pole gets to the dead position, where it tends tc stay, current is cut off from it and sent into another pole. This motor has no dead center, and will start in any position.

1304. *How are the armatures of larger motors made?*

The iron core is in the shape of a cylinder having wire wound over its entire surface, or in grooves upon the surface; the wire is wound in sections, which are connected in series with each other, and are connected with the successive bars of a commutator. A "smooth

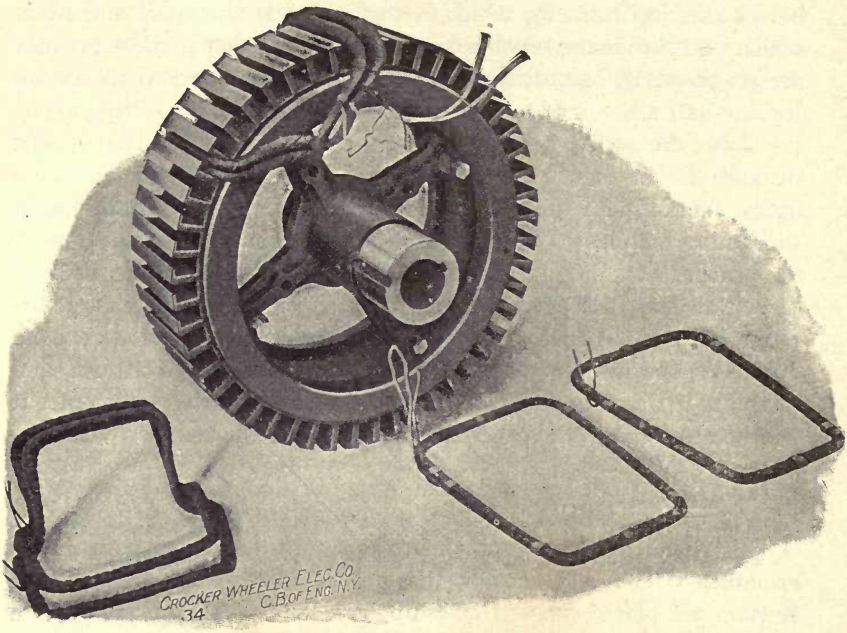


FIG. 1304A.—CONSTRUCTION OF A TOOTHED ARMATURE.

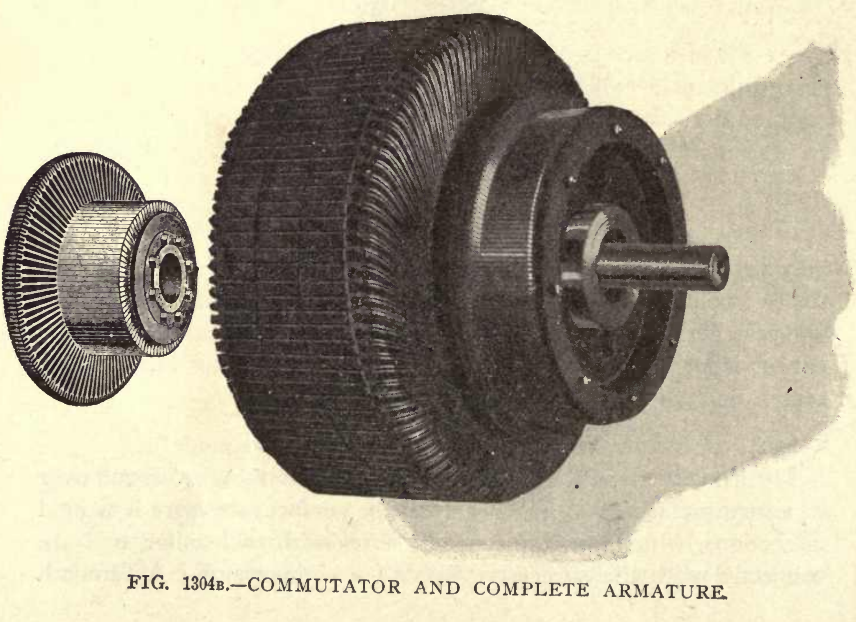


FIG. 1304B.—COMMUTATOR AND COMPLETE ARMATURE.

core" armature has the wire upon the surface, while a "toothed," "slotted" or "tunnel wound" armature has the wires in slots or in holes just below the surface. The figures show the external appear-

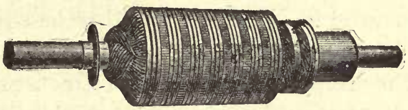


FIG. 1304c.—SMOOTH BODY DRUM ARMATURE.

ance of smooth and toothed core armatures, and the construction of the latter. (See No. 1117.)

1305. *What causes a surface wound armature to rotate when current passes?*

The armature is in a strong magnetic field which becomes distorted more or less by the magnetic effect of the current in each of the wires on the surface. The action of each wire may be considered as something like that shown in Fig. *a,* where there is a strong pull tending to move the wire in between the poles of the magnet. In the case

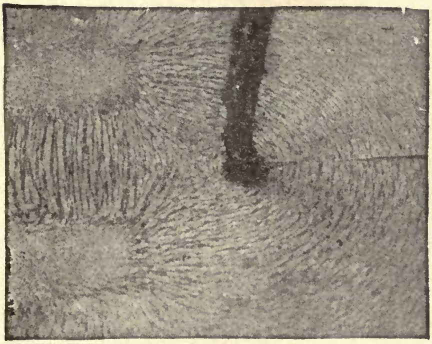


FIG. 1305a.—REACTION BETWEEN CURRENT AND FIELD.

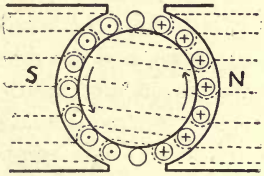


FIG. 1305b.—MAGNETIC FORCES IN ARMATURE

of the actual armature, the lines of force would naturally go into the armature by the shortest path through the air; that is, would go radially. But the magnetic force about the current deflects the lines and makes them traverse a longer path, somewhat as indicated in Fig. *b,* in which circles represent wires, current going toward the paper in those with crosses and toward the observer in those with dots. The effort of the lines to shorten causes the wires to move in the direction indicated by the arrows and thus rotate the iron armature core to which they are fastened. As the wires move to such position that they would pull in the opposite direction, the commutator sec-

tions to which they are connected pass under the brushes, and the current is reversed and they still pull in the same general direction.

1306. *How much is the pull on a single wire carrying current through a magnetic field?*

The pull (measured in dynes) is found to be equal to the product of the strength of the field (measured in lines of force per square centimeter) by the strength of the current (measured in the C. G. S. unit, which equals 10 amps.) and by the length of the wire (in centimeters) which is in the magnetic field. Using grammes, centimeters and amperes, the pull in grammes equals the product of the amperes by the number of lines of force per square centimeter by the number of centimeters length of wire in the field and divided by 9,810. Using English measures, the pull in pounds equals the number of lines of force per square inch multiplied by the number of inches of wire in the magnetic field multiplied by the number of amperes through the wire and divided by 11,303,000.

1307. *How much is the pull on the whole surface of an armature of a motor?*

If the magnetic field is assumed to be of uniform density, we may calculate the pull on each wire as above and multiply by the number of wires on the armature, remembering that the current in each wire is only half the whole current through the armature of a two-pole machine, and considering as the length of each wire only that part that is on the cylindrical surface, neglecting that on the ends. An easier method is to consider the number of lines of force through the armature. The number of dynes pull on the surface, measuring in C. G. S. units, equals the product of the number of lines of force through the armature by the number of wires and by the current divided by the circumference of the armature. The pull measured in grammes equals the product of lines of force by amperes by number of wires divided by the circumference multiplied by 9810. The pull in pounds equals the number of wires by the current by the lines of force divided by 35,525,000 times the diameter in inches. (See No. 1353.)

1308. *Give an example of calculating the pull on an armature.*

Take the case of an Edison bipolar motor taking 80 amps. at 117 volts running at 1400 r. p. m., having 200 armature wires and 2,500,000 lines of force through the armature, which is $6\frac{1}{2}$ ins. in diameter. The pull on the surface is then

$$P = \frac{80 \times 2,500,000}{6.5 \times 35,525,000} = 200 \text{ pounds.}$$

1309. *What is meant by torque?*

By torque is meant the pull at unit radius. In metric system it means the number of dynes pull at a distance of 1 cm. from the center or the number of grammes pull. In English measure it means the number of pounds pull at a radius of 1 in. or of 1 ft. Torque is measured in dyne-centimeters, gram-centimeters, pound-inches or pound-feet. In the case of street railway motors it is common to speak of the torque exerted on the circumference of a wheel 33 ins. in diameter.

1310. *How is the torque calculated?*

The torque in pound-feet equals the product of armature wires by amperes by lines of force divided by 852,500,000. For example, the torque in pound-feet of the above machine is

$$T = \frac{200 \times 80 \times 2,500,000}{852,500,000} = 48 \text{ pound-feet.}$$

1311. *Can the torque be calculated from the power taken by the motor?*

It can, roughly. The above machine takes 80 amps. at 117 volts, or 9360 watts, which, divided by 746, is 12.55 hp; this multiplied by 33,000 gives 414,150 foot-pounds as the energy taken by the motor and given out by it if there were no losses in the motor. Since it makes 1400 r. p. m., the velocity at a radius of 1 ft. is 6.28 times 1400, or 8792 ft. per minute. Dividing the 414,130 foot-pounds by this velocity gives 47.1 as the pull at the radius of 1 ft. This agrees closely with the 48 pound-feet of the previous calculation.

1312. *How can the torque of a motor be actually measured?*

The easiest way is to stop the motor, remove the belt, attach a spring balance to the pulley in such a way as to measure the pull at its periphery. Then, using a rheostat to control the current, send as much current through the armature as is taken in regular working, and measure the pull on the spring. Another way is to clamp a piece of wood to the pulley and arrange a platform scales so as to measure the downward thrust when the motor attempts to start; the scales then weigh the pull at a radius equal to the distance from the center of the shaft to the point where the lever touches the platform. There are several forms of transmission-dynamometer for measuring the amount of power developed by actually weighing the difference between the pull on the tight and on the loose sides of the belt.

1313. *How can the power of a motor be measured?*

A Prony brake is the most convenient method for general use. A

simple form suitable for short tests consists of two blocks curved to fit the pulley and having a long arm and two bolts, as suggested in the figure, and two guide pieces on each side to keep it from slipping off sideways. The end of the arm rests upon a sharp edge, which is

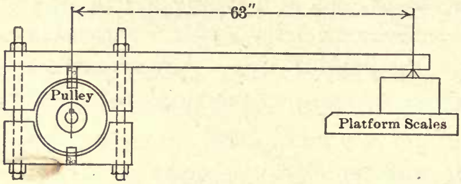


FIG. 1313.—PRONY BRAKE.

supported upon the platform of a scale. The scale measures the torque at a radius equal to the distance from the center of the shaft to the knife-edge. If in a given case the pressure is 5 lbs. at the distance of 63 ins., the torque is 315 pound-inches, or 26.25 pound-feet.

1314. *Can the work done by a motor be measured by such a device?*

It is only necessary to let the motor run and then measure the pressure on the scale and also measure the speed. The power equals the product of the torque by the velocity at that radius. The calculations are simplified if the distance is 63 ins., for then the circumference of the circle passing through the knife-edge is 33 ft., so that 1 lb. pressure at 1000 r. p. m. would mean 33,000 foot-pounds, or 1 hp. In such a measurement it is desirable to lubricate the blocks by soapy water or by a ham-rind, to prevent jerky action.

1315. *Give an example of a test on a Prony brake.*

Suppose the arm is 63 ins. long, the pressure is 8 lbs. and the speed is 1400 r. p. m. Then the point at the knife-edge would travel 33 ft. in each revolution, which at 1400 per minute would be 33 × 1400, or 46,200 ft. per minute. Now, multiplying this by 8 gives 369,600 foot-pounds work done per minute. But 33,000 foot-pounds make 1 hp, hence dividing by 33,000 gives 11.2 as the horse-power.

1316. *How can the efficiency of a motor be determined?*

Connect an ammeter in series with the motor and a voltmeter across its terminals, so as to measure the electrical energy supplied. Measure the mechanical work given out by the Prony brake. Reduce both to horse-power or watts and divide the work given out by that absorbed.

1317. *Give an example of measuring efficiency.*

Suppose the motor measured in No. 1314 takes 84 amps. at 117

volts. The electrical energy taken is then 84×117, or 9828 watts, or 13.2 hp. Dividing that delivered by that received gives $11.2 \div 13.2 = 0.85$, or 85 per cent, as the commercial efficiency of the motor at that load.

1318. *How can the efficiency at different loads be determined?*

By clamping the two blocks together more or less tightly, the load may be varied, and so the electrical and mechanical power may be measured for different loads.

1319. *How can one tell how much power a motor is giving out when it is in regular service driving machinery?*

If the motor can be cut loose from the regular load and a brake applied, the efficiency may be determined for different currents as above indicated. Then by measuring the current and voltage while it is working at its regular load and multiplying by the efficiency of the motor for such load, we can determine the power being delivered.

1320. *Of what material is the field magnet of a motor usually made?*

Wrought iron, cast iron and cast steel are used. Wrought iron has higher permeability than either of the others; this allows the

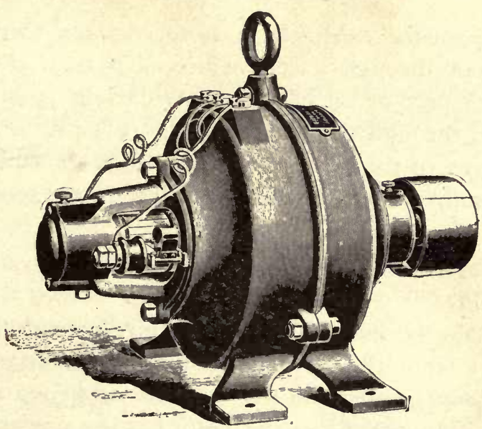


FIG. 1320.—MOTOR WITH IRONCLAD FIELD.

magnetic field to be made more dense, and therefore the whole machine may usually be made smaller for a given power. Cast iron costs less per pound and can be cast into the required shape more cheaply than wrought iron can be forged or punched. Cast steel, containing but a very small percentage of carbon, can now be obtained in any desired form of casting, and is rapidly displacing cast iron because its magnetic properties are almost as good as those of wrought iron, while it costs but little more than cast iron. For very

small motors, hardened tool steel is sometimes used, being permanently magnetized so that no field magnetizing coil is necessary.

1321. *How is the field of a motor usually magnetized?*

The hardened steel magnets sometimes used with the small motors are magnetized by being placed between the poles of a strong magnet or by passing a strong current through a coil placed temporarily

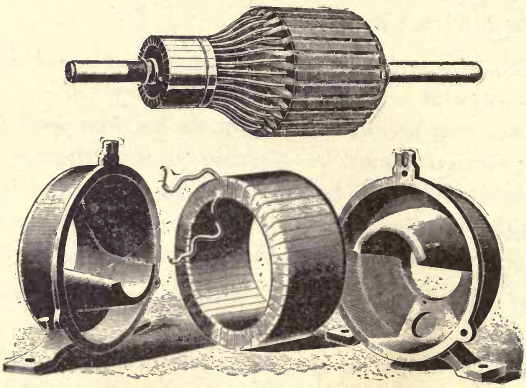


FIG. 1321.—ARMATURE, FIELD COIL AND CASTINGS.

around the hardened steel. It is more common to magnetize the field by current through a coil, which is part of the motor, and through which part or all of the motor current passes. If all the current passes through the field coil, it is called a "series coil." If only a small part of the current passes through the coil, it is called a "shunt field coil." Sometimes motors have both series and shunt field coils.

1322. *What are the advantages and disadvantages of using permanent magnets?*

The advantage is that they do not require a continuous expenditure of energy while the motor is running. The disadvantages are that a permanent magnet can not be made as strong as an electromagnet of the same size, hence the motor has less power; the strength of such a magnet would gradually become less, so that the speed of the motor for a given voltage would increase.

1323. *Under what conditions are series motors used?*

Small motors for use with primary batteries are commonly wound as series machines, likewise motors of any size intended for use on arc-light circuits in which the current is of constant strength. Series motors are also used on constant-potential circuits, as in railway work and for similar purposes where an attendant is always at hand to regulate or control the speed.

1324. *What are the advantages and disadvantages of series motors?*

Series coils are somewhat cheaper to wind than shunt coils, because the wire is larger, costs less per pound and less labor is needed to wind comparatively few turns of large wire than to wind many turns of small wire. This is particularly true of small machines. Series motors are more easily started, especially under heavy loads. They maintain the speed more nearly constant than do shunt motors when on circuits in which the current is maintained at constant strength. When on constant potential circuits, such as used for incandescent lighting or for electric railways, the speed of a series motor will depend upon the load.

1325. *How are series motors started on battery circuits?*

Small series motors operated by battery power are started by sim-

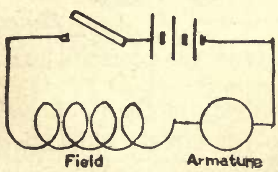


FIG. 1325.—CIRCUIT OF SMALL BATTERY MOTOR.

ply closing a switch to complete the circuit, as indicated in the figure. The resistance of battery and motor is sufficient to prevent too great a rush of current at the start.

1326. *How are series motors started on arc-light circuits?*

Motors of arc light or "series" circuits are connected into the circuit in the same way as arc lamps. Some of them are provided with a simple single-pole switch that short-circuits the motor when not running, as shown in the figure. To start the motor, this switch is

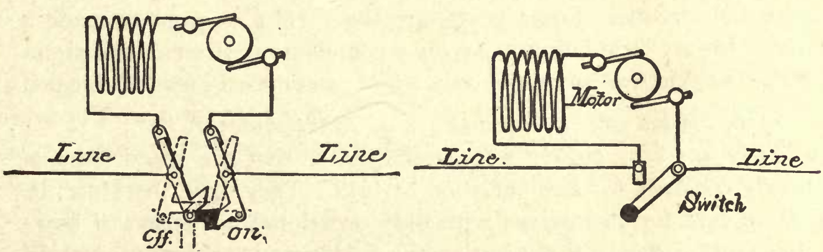


FIG. 1326.—SERIES MOTOR ON CONSTANT CURRENT CIRCUIT.

opened, or thrown to the "on" position, thereby sending the current through the motor instead of through the switch. No rheostat or

resistance is needed, since the current through the motor can not be greater at the start than when in regular running, this being kept constant by the dynamo. It is better to use a double-pole short-circuiting switch, in order to cut the motor entirely free from the circuit when not running; in fact, this is required by the insurance rules. Such motors require the use of high voltages, do not regulate satisfactorily and have gone almost entirely out of use.

1327. *How are series motors started on constant voltage circuits?*

It is necessary to have some auxiliary resistance in series, as shown in the figure, to prevent too great a rush of current at starting. The

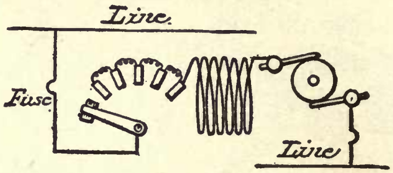


FIG. 1327.—SERIES MOTOR ON CONSTANT POTENTIAL CIRCUIT.

resistance of a 15-hp railway motor is only about 2 ohms. If this were connected to a 500-volt circuit while standing still and without any extra resistance, the current would be something like 250 amps. at the first rush, or more than 150 hp. By introducing more resistance into the circuit at first, the rush of current is reduced and the motor starts gradually. As the motor comes up to speed, the extra resistance is gradually cut out. (See also No. 366.)

1328. *How are series motors stopped?*

The operations in starting are simply reversed, care being taken to move the switches quickly in order to avoid excessive flashing.

1329. *On what kind of circuits are shunt motors used?*

Shunt motors are used almost without exception on constant-potential circuits. Some years ago the C. & C. Company made a motor for arc light circuits, having a combination of series and shunt coils, but this was about the only shunt motor used on such circuits.

1330. *What are the advantages of shunt motors?*

They are very closely self-regulating, so that the speed remains nearly constant for any variation of load. They may, therefore, be left to care for themselves with only occasional inspection of bearings and brushes. By adjusting the field current, the speed may be changed through a range as great as four to one with some motors.

1331. *What are the disadvantages of shunt motors?*

The shunt motor requires somewhat more care in starting than does a series motor. It does not start under a heavy load so easily

as do series motors. In case the current should be cut off for any reason, and the motor should not be disconnected from the line before the current comes on again, the motor is more liable to be burnt out than would be the case with a series motor.

1332. *How is a shunt motor started?*

A shunt motor is generally provided with two switches, as indicated in the figure. The double-pole switch, *A,* is first closed, thus sending current through the field coil, *B*. The arm of a rheostat, *D,*

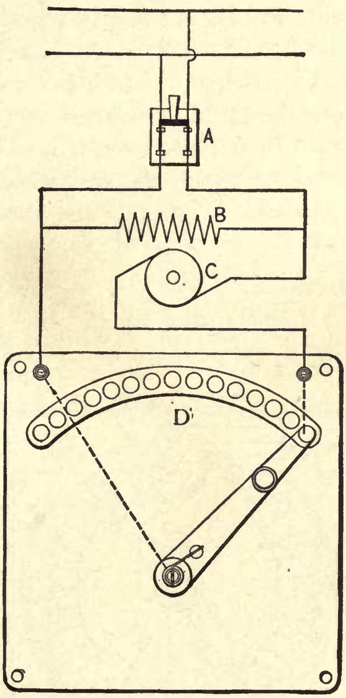


FIG. 1332.—CIRCUITS OF SHUNT MOTOR.

is then moved slowly, so as to allow a moderate amount of current to pass through the armature, *C*. As the armature begins to revolve and to come up to speed, the resistance is gradually cut out from the rheostat, until it is all out when the arm rests upon the last button.

1333. *How is a shunt motor stopped?*

The double-pole main switch should be opened first, and as soon as the motor has come to rest, the rheostat arm should be moved back to the "off" position. If the rheostat arm is moved back first,

there is apt to be vicious sparking when the last point is reached; also when the main switch is opened, there is apt to be a long arc that endangers the insulation on the field coils. Some of the automatic starting rheostats are arranged to take care of themselves so that one needs only to pull the main switch.

1334. *What is meant by an "automatic rheostat?"*

This expression may refer to any of several different devices. The more common use is with reference to motor starting rheostats which have some magnetic device to throw the starting resistance into series with the armature in case the line voltage is removed for any cause. Such are called "automatic motor starting rheostats with 'no voltage' release." Others have, in addition, a device to throw the starting resistance into the armature circuit and thus stop or slow down the motor in case of excessive overload. The term is also applied to starting devices in which the resistance is cut out of the armature circuit automatically without the direct control of the operator.

1335. *How are automatic motor starting rheostats arranged?*

The rheostat arm carries a spring which tends to throw it back to the "off" position, also the armature of an electromagnet, whose coil

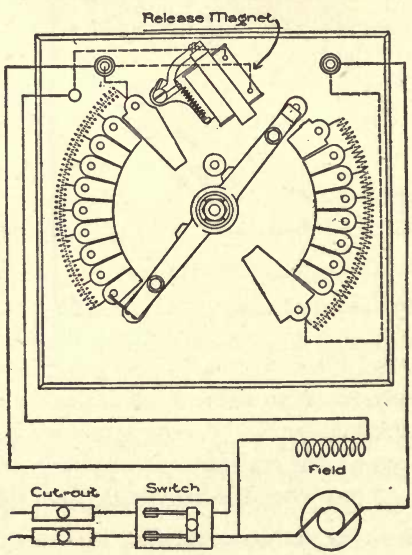


FIG. 1335.—MOTOR RHEOSTAT WITH "NO VOLTAGE" RELEASE.

is in series with the shunt field coil of the motor. As soon as the current is thrown on at the main switch, both the motor field magnet

and the rheostat release magnet are energized; and the rheostat arm is magnetically held in position when it has been moved to the running position. When the main switch is opened, or the pressure is removed from the line from any external cause, the current ceases flowing around the release magnet, so that it lets go and the spring throws the arm back to the "off" position. This is called a "no-voltage" release. In the form shown in Fig. 1335, the rheostat arm is held or released by a projecting hook that engages with the pivoted armature of the electromagnet. (See also Fig. 1341.)

1336. *Why does the release magnet hold the rheostat arm after the main switch has been opened and until the motor has come nearly to rest?*

This is because the shunt motor runs in the same direction that the machine would run as a dynamo. When the armature of the motor is revolving in the magnetic field, it generates an E.M.F. just as it would if it were working as a dynamo. When working as a motor, this is in the opposite direction to that on the line, and is called a "counter electromotive force," or "C.E.M.F." The instant the current ceases to come from the outside source, this C.E.M.F. becomes active and maintains current through the coils of the field and the release magnets, thus keeping up the magnetism until the speed of the machine falls off almost to a stop. (See No. 1346.)

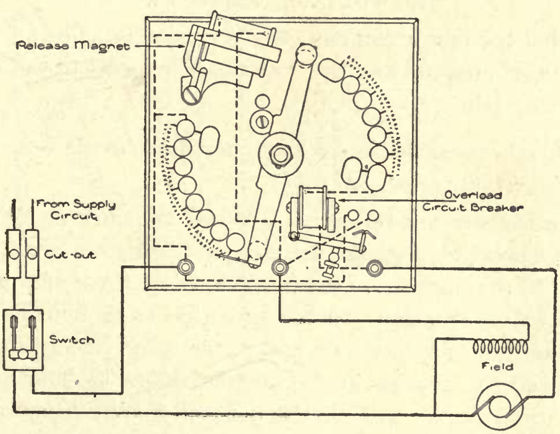


FIG. 1337.—AUTOMATIC MOTOR SWITCH WITH "OVERLOAD" AND "NO VOLTAGE" RELEASES.

1337. *How are automatic motor starting rheostats arranged to open the circuit in case of an excessive load?*

They have an auxiliary magnet whose coil is in series with the mo-

tor armature. In case the current becomes greater than is safe, the "overload" magnet lifts its armature, which either trips a spring switch in the armature or main circuit, or else short-circuits the "no-voltage" release magnet, which then lets the rheostat arm fly back and open the armature circuit or leave it closed through so high a

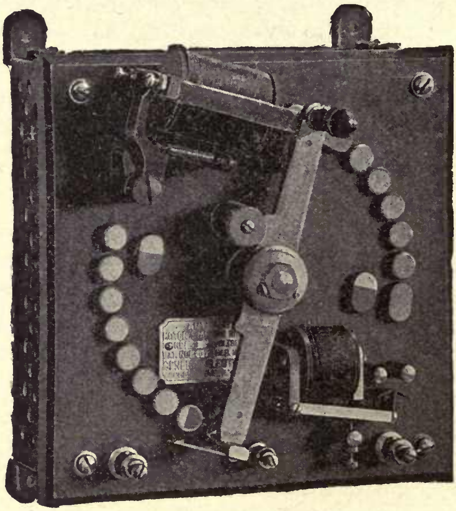


FIG. 1337A.—AUTOMATIC MOTOR SWITCH WITH "OVERLOAD" AND "NO VOLTAGE" RELEASES.

resistance that the motor can run only very slowly. The figures show the "no-voltage" magnet and the "overload" magnet in a well-known type of starting box.

1338. *What causes the long flash if the field circuit is opened after the armature circuit is opened?*

This is caused by self-induction. When the current through the magnet coil begins to stop, the magnetism begins at once to weaken. The change in the number of magnetic lines of force sets up or "induces" an E.M.F. that is in such a direction as to tend to maintain the current in the same direction and at the same strength as before; the more rapid the change in the magnetization and the larger the number of turns in the coil, the higher will be the induced E.M.F. This tends to maintain the current even through the air gap as the switch is opened. In the case of a shunt machine, the E.M.F. due to opening the field circuit is likely to be many times as great as the regular working voltage, and is liable to cause a spark to jump through the insulation and either "ground" or "short-circuit" the field coil.

1339. *Why is the flash prevented by leaving the armature circuit closed until after the motor has stopped?*

There are two reasons: first, because the armature offers a path of low resistance for the induced current, and, second, because the armature tends to maintain the magnetizing current until rotation stops.

1340. *How does the presence of a closed circuit prevent the flash?*

When the field coil is shunted by the armature or by some other path, such as a pilot lamp, the E.M.F. of self-induction from the dying down of the magnetism causes a current to flow through the coil and around through the armature or lamp circuit; this current is in the same direction as that which came from the line, and it therefore tends to keep up the magnetization. Thus, if there is a closed circuit the induced current delays the demagnetization and so reduces the induced E.M.F.

1341. *Are automatic rheostats ever arranged to prevent induction when the line switch is opened, after the automatic has opened?*

In some starting boxes the end of the field circuit is permanently connected to the first live segment or button of the rheostat, an extra

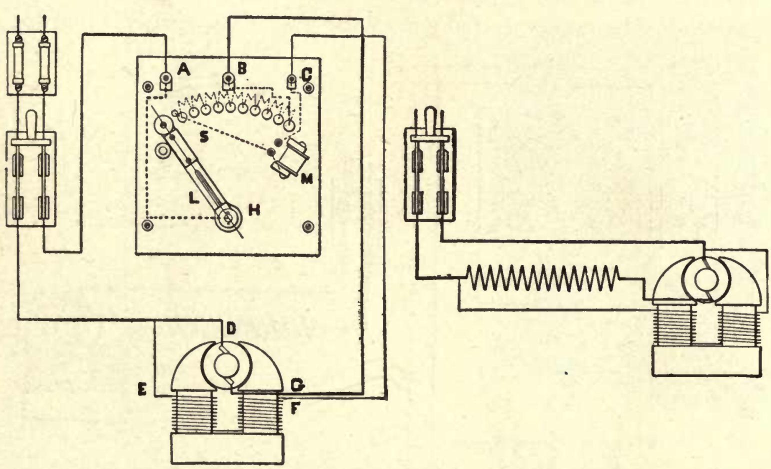


FIG. 1341.—STARTING BOX PROPERLY CONNECTED.

button being placed at the retaining magnet so as to cut the resistance out of the field circuit at the last step. This is shown diagrammatically and as actually made in the accompanying sketches.

1342. *How are incandescent lamps arranged to take up the kick of the field coil?*

A simple arrangement is shown in the sketch, in which one, two or five 110-volt incandescent lamps are connected in series between the armature and the field terminals of the starting box. One lamp

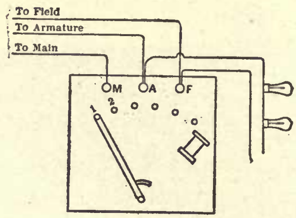


FIG. 1342.—FIELD SAFETY LAMPS.

is used on a 110-volt motor circuit, two on a 220-volt circuit and five on a 500-volt circuit. This arrangement has practically the same effect as that shown in the preceding number, and is applicable to any automatic starting box.

1343. *Is there any risk in getting the motor starting box connected improperly?*

If the heavy wires from the motor are mixed, as shown in the figure, the field circuit is shunted around the armature when starting, instead of being connected across the line. The result is that the

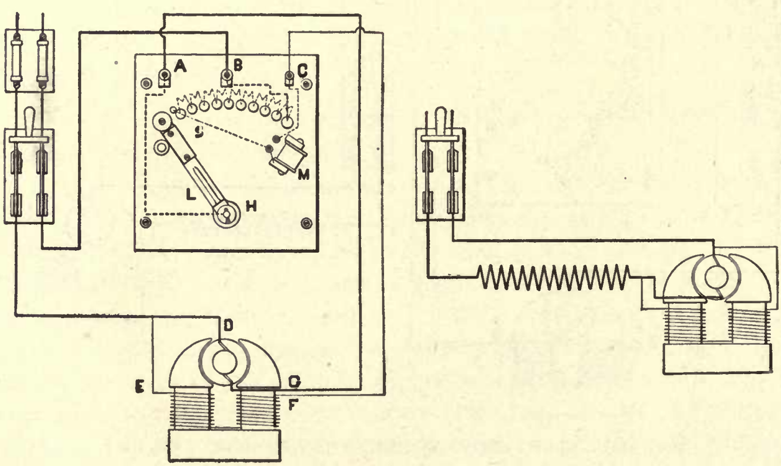


FIG. 1343.—STARTING BOX IMPROPERLY CONNECTED.

field is very weak when it should be strong, and the motor will require an excessive current for starting and may blow the fuses or

burn out the motor. The condition is shown more simply in the second sketch.

1344. *How can shunt motors be started and stopped safely from a distant point?*

A common method is to place the starting rheostat and the main switch at the point desired and to run the two main wires and the field wires from that point to the motor. This often requires considerable extra length of wire, which means additional cost in wiring and additional loss on the line.

1345. *How can shunt motors be started automatically so that the operator need only close or open a single switch?*

Several devices are used. At the left of the figure is one suitable for small motors; when the main switch is closed, current passes through the field coils and thence through a starting solenoid *a*, which then attracts the iron plunger *C*, which in turn raises the shoe *EF* so as to make contact with one after another of the rheostat contacts *B*; the solenoid thus closes the armature circuit through the starting rheostat and then cuts out the resistance a step at a time; by means of the dash pot *d* and valve *e*, the motion may be made

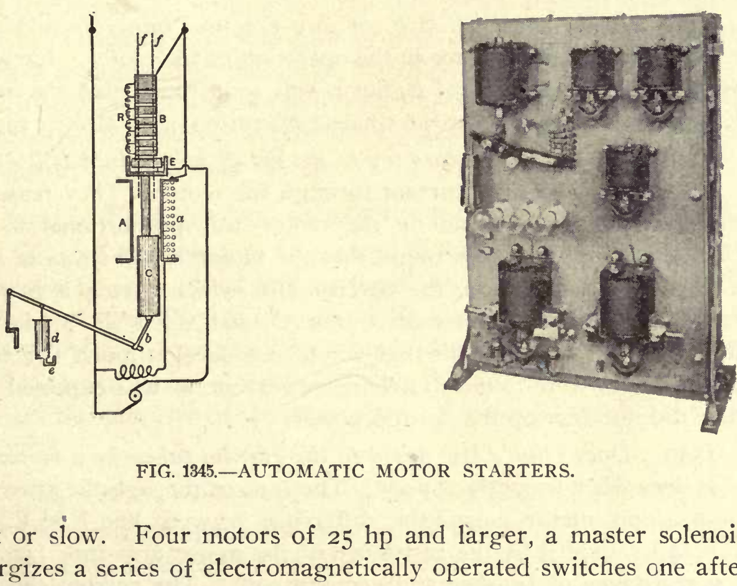


FIG. 1345.—AUTOMATIC MOTOR STARTERS.

fast or slow. Four motors of 25 hp and larger, a master solenoid energizes a series of electromagnetically operated switches one after the other, and these in turn cut out the starting resistance one step at a time; the main circuit is closed and opened by a solenoid circuit-

maker-and-breaker having magnetic blow-outs for disrupting the arcs.

1346. *How is the magnetization of a shunt motor maintained after the line current is cut off?*

The magnetizing current is caused by the E.M.F. due to the rotation of the armature in the magnetic field. When the motor is driven by current from the line, an E.M.F. is generated in its armature just as in a dynamo. When the machine is running as a motor, this E.M.F. is in a direction tending to prevent current from passing through the armature from the line. When the line current is cut off for any reason, the motor E.M.F. sends current through the field coil in the same direction as the previous current from the line, as indi-

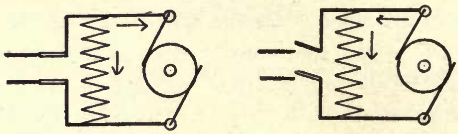


FIG. 1346.—DIRECTION OF CURRENT IN SHUNT MOTOR.

cated by the arrows in the figure at the right. (The direction of the currents from the line is shown in the figure at the left.) The motor then acts as a shunt dynamo, exciting its own field until the speed drops off. (See No. 1336.)

1347. *Is the motor E.M.F. of any practical importance?*

It is of great importance in the operation of the motor. Early inventors tried to get rid of it, but it was soon found that the motor E.M.F. was necessary for the efficient operation of an electric motor.

1348. *Why did inventors try to get rid of motor E.M.F.?*

Because it limits the current through the motor. They reasoned that the power delivered by the motor was proportional to the current taken. But they found that the motor E.M.F. was in such a direction as to oppose the current (for which reason it is often called a "counter electromotive force," or "C.E M.F."), and so they tried to make motors that would not develop much C.E.M.F. Such motors were found to take more current, as was expected, but they did not develop the desired power.

1349. *Does Ohm's law apply to the current taken by a motor?*

It does when properly applied. The current through the armature of a shunt motor equals the difference between line E.M.F. and C.E.M.F. divided by the resistance of the motor armature (including resistance of brushes and commutator). The current through the field of such a motor is simply the pressure divided by resistance.

1350. *Why do motors with small C.E.M.F. develop but little power?*

Because the same elements in a motor that cause it to deliver power are also the elements causing the C.E.M.F. In fact, it is now understood that the power given out by a motor equals the product of the current by the C.E.M.F.

1351. *What determines the power given out by a motor?*

The power depends upon the pressure and current supplied to the motor, the current being regulated by the amount of work put upon the motor, as will be explained. In order not to get into too great complication at first, it may be presumed that the motor has a steady load and is working properly. The work being done by the motor and the electrical energy taken from the line may then be analyzed.

1352. *What elements compose the power delivered by the belt of a motor?*

The mechanical power equals the product of the speed by the pull on the belt. For example, if the belt is running at 55 ft. per second, and the pull on the belt (or rather the difference between the pulls on the tight and loose sides of the belt) is 10 lbs., the power is 550 foot-pounds per second, or 1 hp. Making allowance for small losses in friction and in heating the iron core of the armature, the product of belt speed by pull equals the product of the pull on the armature wires multiplied by the speed at which they move. (In the case of toothed armatures, the pull comes upon the teeth more than upon the wires themselves, but the theory may be extended without great difficulty to cover that case.)

1353. *What elements make up the pull on the armature wires?*

The pull on each wire (measured in dynes) equals the product of current by strength of field by length of wire in the magnetic field. The pull upon the whole armature is the product of the number of wires by the current through the armature by the effective number of magnetic lines of force through the armature divided by 3.14 times the diameter of the armature. (See also Nos. 1306, 1307 and 1308.)

1354. *What elements make up the velocity of the armature wires?*

The velocity equals the number of revolutions by the distance around the armature. The latter is, of course, the circumference of the armature (considering the average position of the wires) and is 3.14 times the average diameter.

1355. *What elements compose the power delivered to the shaft or pulley of the motor?*

This equals the product of the pull upon the armature wires multiplied by their speed. In multiplying the factors of the two elements, as given in Nos. 1352 and 1353, it is seen that "3.14 times the diameter" multiplies one factor and divides the other, so that the two cancel. The final product for the work is: Armature current multiplied by number of armature wires by effective number of magnetic lines through armature by number of revolutions per second.

1356. *What elements compose the C.E.M.F.?*

The counter, or motor, E.M.F. equals the rate of cutting lines of force and is the product of the number of armature wires by the number of revolutions per second by the effective number of magnetic lines of force through the armature. (This gives the E.M.F. measured in the absolute or "C. G. S." unit, which is only one one-hundred-millionth part of a volt.)

1357. *What is the relation between power and counter electromotive force?*

From Nos. 1354 and 1355 it is seen that the power equals current multiplied by the product of wires by revolutions by lines of force, which equals current by C.E.M.F. Thus it is seen that while the C.E.M.F. limits the current, it is one of the factors of the power. (In the case of alternating-current motors, the power of the motor equals the product of current by the part or component of the C.E.M.F. which is in phase with current, this product being multiplied by another factor depending upon whether it is a single phase, two-phase or three-phase system.)

1358. *For what sort of a motor does the above reasoning apply?*

For simplicity, the above has been developed only for a bipolar direct-current motor, but the argument might be modified to apply to any kind of a motor, and the general conclusion applies to any electric motor.

1359. *What units were used in the above argument?*

For simplicity, the units of the metric or "C. G. S." system were used. The conclusion, however, in No. 1356 is independent of the units used.

1360. *What is meant by "effective magnetic lines of force"?*

In a dynamo or motor the brushes are so set, or the magnetic field is so distributed, that the E.M.F. in some of the wires is in the opposite direction to that in the rest. Sometimes this is to diminish the

sparking at the brushes, or is due to incorrect design or to improper setting of the brushes. For this reason the effective number of wires or of magnetic lines is less than the total. We may consider either that not all the wires are effective, or that not all the lines are effective.

1361. *Does the power delivered by a motor increase as the C.E.M.F. increases?*

The two vary inversely so long as the C.E.M.F. is more than half of the line E.M.F. This is because the current is controlled by the C.E.M.F., being equal to the difference between the line voltage and the C.E.M.F. divided by the resistance of the armature circuit. The power equals the product of current by C.E.M.F., and it follows that the power increases as the C. E. M. F. decreases, so long as the difference between the two E.M.F's increases faster than the C.E.M.F. decreases.

1362. *Give an example to illustrate this point.*

Assume the line pressure to be 100 volts, the armature resistance to be 1 ohm and the C.E.M.F. to be 90 volts; the current is 100 minus 90 divided by 1, or 10 amps.; the power delivered by the motor is 10 multiplied by 90, or 900 watts; while the power taken by the motor is 10 multiplied by 100, or 1000 watts. Now, suppose the C.E.M.F. drops to 60 volts; the current is 100 minus 60 divided by 1, or 40 amps.; the power delivered is 40 multiplied by 60, or 2400 watts. Suppose the C.E.M.F. is 50 volts; the current is 50 amps., and the power delivered is 2500 watts. Suppose the C.E.M.F. is 20 volts; the current is 80 amps., and the power delivered is 1600 watts. It is thus seen that the power increases until the C.E.M.F. equals half the line E.M.F., after which the power becomes less, although the current continues to increase. (As a general rule the safe current carrying capacity of the armature will be passed before the C.E.M.F. drops to 50 per cent of the line voltage.)

1363. *What is meant by the efficiency of a motor?*

The efficiency of any machine is the ratio of the power delivered to that received. The total power given out by a direct-current motor is the product of the armature current by the C.E.M.F. The net power delivered is something less than this by an amount equal to the heat loss in the armature core plus the friction at the brushes, bearings and against the air. The total power received by the motor equals the sum of the electrical energies given to the armature and to the field. We may distinguish between the electrical and the commercial efficiency of a motor.

1364. *What is meant by the electrical efficiency of a motor?*

The electrical efficiency of a motor is the ratio of the product of armature current by C.E.M.F. to the total electrical energy supplied to the motor. Neglecting the small amount taken by the field we may say that the electrical efficiency is the ratio of the energies in the armature; that is, the product of armature current by total voltage across the armature divided by the product of the armature current by the C.E.M.F. Since the current is the same in numerator and denominator, we may cancel it and say that the electrical efficiency is the total voltage divided by the C.E.M.F. (The above refers only to direct-current motors, for in A. C. motors the C.E.M.F. may be smaller or larger than the line voltage, and the product must be multiplied by a factor depending upon the difference of phase between current and pressure. (See also No. 1357.)

1365. *What is meant by the commercial efficiency of a motor?*

The commercial efficiency is the ratio of the power delivered from the pulley to the total electrical energy received.

1366. *How can the C.E.M.F. be measured?*

It can not be measured directly. It can be calculated by taking the difference between the total pressure at the terminals of the armature and the product of armature current by the resistance of the armature.

1367. *Show how the efficiency of the motor is affected by changes of C.E.M.F. in the above case (No. 1362).*

When the C.E.M.F. is 90, the energy taken by the motor is the product of current by volts, 10 times 100, or 1000 watts; the power delivered is 900 watts, making the efficiency of the motor to be 900 divided by 1000, or 90 per cent. When the C.E.M.F. is 20, the power taken is 80 times 100, or 8000 watts, while the power delivered is 1600 watts, and the efficiency is 20 per cent. The efficiency is thus seen to be equal to the C.E.M.F. divided by the line E.M.F.

1368. *How does the C.E.M.F. affect the starting of a motor?*

When a motor is standing still, there is no C.E.M.F. due to armature rotation, and the current taken at first is governed principally by the resistance of the circuit. If the motor is series wound, there is a transient C.E.M.F. due to self-induction for a few seconds during the rapid building up of the magnetic field. If the motor is shunt wound, self-induction delays the current through the field coil, but that through the armature is not impeded much from such cause. As soon as the armature begins to rotate, the motor E.M.F. begins to

develop and the resistance may be cut out gradually from the starting box as the armature comes up to speed. Thus C.E.M.F. gradually replaces ohmic drop in limiting the current as the motor starts.

1369. *What governs the current taken when the motor is running at full speed?*

At a given load and speed, the current is governed by the C.E.M.F. and the resistance of the armature circuit (neglecting the small current through the field), and the pull on the belt is just enough to turn the shaft at the right speed. If an additional load is put on, the pull on the armature for an instant is not large enough, and it begins to slow down; this reduces the C.E.M.F., which allows greater current to pass and increase the pull on the armature and so bring the armature up toward its original speed. If the voltage on the line remains constant and if the magnetic field of the motor is not changed, the armature will run somewhat slower as the load increases.

1370. *Does the resistance of the armature have much to do with the amount the speed slows down?*

The less the resistance of the armature, the more nearly the C.E.M.F. equals the line voltage, and the less reduction of C.E.M.F. necessary to allow the greater current to pass. Hence the speed of the motor will be more constant for varying loads as the resistance of the armature is less.

1371. *How does armature resistance affect the efficiency of a motor?*

The efficiency is higher as the armature resistance is lower. The voltage of the line is balanced by the sum of the C.E.M.F. and the ohmic drop through the armature. The ohmic drop equals the product of current by resistance. Hence, for a given current, the less the resistance the less will be the ohmic drop and the greater will be the voltage left to balance the C.E.M.F. As was seen in No. 1360, the efficiency is greater as the C.E.M.F. is greater; hence, the less the resistance of the armature, the greater will be the efficiency of the motor.

1372. *Can the resistance of the armature be changed?*

Only by rewinding it. It should be remembered, however, that part of the resistance of the armature circuit is at the contact between the brushes and commutator. Therefore, a motor with dirty or uneven commutator, loose brushes and poor connections will not run at so uniform speed as the same one when put into first-class run-

ning order. Any excessive heat around the brushes or holders should therefore be investigated.

1373. *What regulates the speed of a motor?*

The speed of a motor is governed by the resistance of its armature circuit and by its C.E.M.F. Enough current must pass through the armature (with a given magnetic field) to make the torque or pull equal to the load. This current multiplied by the resistance of the armature circuit gives a certain ohmic drop. The C.E.M.F. must equal the difference between this and the line voltage. With a given magnetic field and armature, the only variable element in the C.E.M.F. (see No. 1356) is the speed. This, therefore, must be such as to bring the C.E.M.F. to such a value that the difference between it and the line voltage will just send sufficient current through the armature to give the necessary torque.

1374. *How can the speed of a motor be increased with a given load?*

The speed of a motor on a constant-potential circuit can be increased either by reducing the resistance in the armature circuit or by weakening the magnetic field, that is, by reducing the effective number of magnetic lines of force through the armature.

1375. *To what extent can the speed be regulated by changing the resistance of the armature circuit?*

The speed may be reduced to any amount desired by putting enough resistance in series with the armature. This is not economical, however, for all the pressure lost in the resistance (when multiplied by the current) represents lost energy wasted in heating the resistance. The speed increases as the resistance is cut out from the circuit and the upper limit is reached when all the adjustable resistance is out.

1376. *How can the power delivered by a motor be increased?*

The power equals the product of speed by torque or pull. Either or both of these may be varied by changing either the voltage at the terminals of the armature or by changing the effective number of magnetic lines of force through the armature.

1377. *How can the effective number of magnetic lines of force through the armature of a motor be changed?*

Either by shifting the brushes or by changing the number of ampere turns in the field-magnet coil. As a general rule, it is not advisable to shift the brushes far from the neutral plane, lest excessive sparking damage brushes and commutator.

1378. *How does a change in the effective number of magnetic lines of force through the armature affect the torque in the case of a motor on a constant-current circuit?*

The torque is proportional to the product of current by armature wires by lines of force. (See Nos. 1306 to 1309.) In a constant-current circuit, such as an arc light line, the effective number of armature wires or the effective number of lines of force may be varied to some extent by shifting the brushes. The total number of lines of force may be varied by changing the number of ampere turns through the field coil. The latter may be varied either by connecting a shunt of variable resistance around the field coil or by having a number of terminals so that the part of the coil may be cut out.

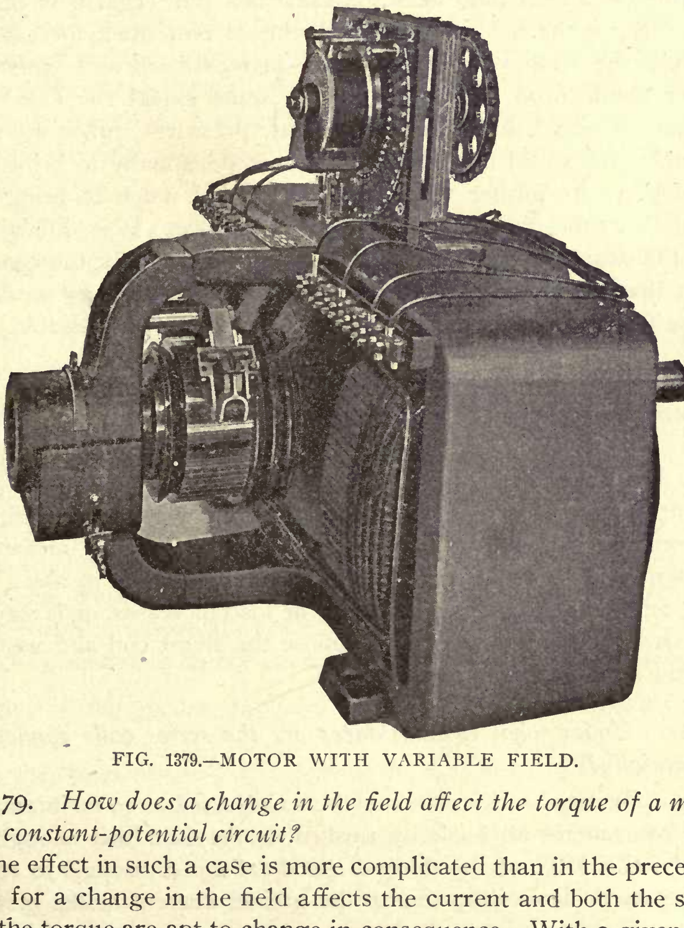


FIG. 1379.—MOTOR WITH VARIABLE FIELD.

1379. *How does a change in the field affect the torque of a motor on a constant-potential circuit?*

The effect in such a case is more complicated than in the preceding case, for a change in the field affects the current and both the speed and the torque are apt to change in consequence. With a given cur-

rent, the torque would be increased by strengthening the field; but the stronger field increases the C.E.M.F. for the same speed, and this reduces the current. Under ordinary conditions it is found that strengthening the field of a motor on a constant-potential circuit causes a more than proportional decrease of current. The result is that within the limits met in ordinary practice, the torque and the power of a motor on constant-potential circuit are actually increased by weakening the field.

1380. *How does a change in the field affect the speed of a motor on a constant-potential circuit?*

Weakening the field causes the armature to run faster. Suppose a motor has a load that takes the same belt pull regardless of the speed. Since the field is weakened, the current must increase to maintain the torque constant. This increased current causes a greater ohmic drop and so reduces to some extent the C.E.M.F. necessary to equal the balance of the line pressure. Since the field is weaker, the speed must be increased proportionally to bring the C.E.M.F. to its former value and almost that much to bring the C.E.M.F. to the new and slightly smaller value. It is difficult to show the exact relationship without using algebra, but the conclusion is that for the same belt pull the speed is increased by weakening the field. A range of four to one is sometimes practicable.

1381. *What is the common method of regulating motors?*

Motors on constant-potential circuits are generally plain shunt motors. When it is desired to adjust the speed accurately, a rheostat is cut into the field circuit. In some cases the motor is compound wound; that is, it has two field coils, one of fine wire shunted around the armature and one of coarse wire in series with the armature. The series coil may be cumulatively connected so as to assist the shunt coil and strengthen the field as the load increases, or it may be connected differentially so as to oppose the shunt coil and weaken the field as the load increases.

1382. *Under what circumstances are the series coils connected differentially?*

The differential series coils may be so adjusted as to maintain the speed constant at all loads by weakening the field just enough so that the C.E.M.F. at the desired speed falls just enough to equal the increased ohmic drop due to the greater current at the greater load.

1383. *Under what conditions are the series field coils connected cumulatively?*

The series coils are connected so as to strengthen the field due to the shunt coils when the motor must start under heavy load or when the load is subject to great fluctuations and when exact regulation of speed is of less importance than disturbances of the line pressure. In some cases the armature reaction weakens the field so much that the series coils must be connected cumulatively to keep the field strong enough and so maintain constant speed.

1384. *Why do some plain shunt motors run at almost constant speed at any and all loads?*

By making the motor with very strong field the armature wires may be made fewer and consequently of lower resistance. For reasons given in Nos. 1369 to 1372, the motor regulates more closely as the armature resistance is less. Some motors also are so designed that the magnetizing force of the current through the armature coils weakens the field just enough to maintain the speed constant at all loads.

1385. *Why are series motors used on street railways?*

Because of their great starting power, the ease of controlling the speed, the smaller cost of winding the field magnet coils.

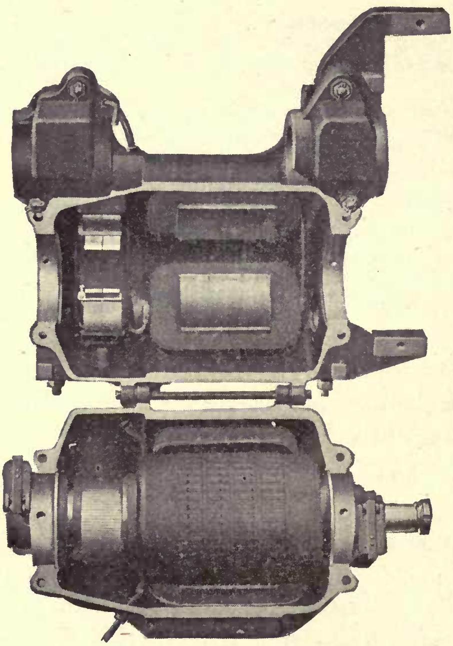
1386. *Why do series motors have greater starting power than shunt motors?*

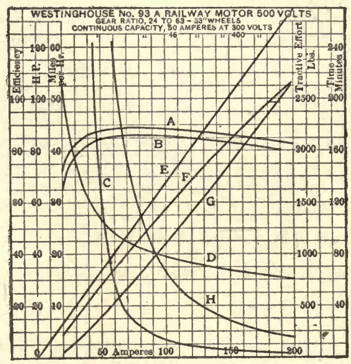
Since the whole of the armature current passes through the field coils, the magnetic field is strongest when the armature current is greatest. This occurs at the time of starting, for when the motor is standing still the C.E.M.F. is small. The torque is very great, since both the field and the current through the armature are strong. Resistance is placed in series with the motor to prevent too great a rush of current, which would start the car with an uncomfortable jerk. As the car begins to move, the resistance is rapidly cut out and C.E.M.F. replaces ohmic drop in regulating the current taken by the motor.

1387. *What governs the final speed of a series motor when pulling a car?*

As the speed of the car increases, the C.E.M.F. of the motor increases for a given current. This reduces the current and consequently the field strength, both of which reduce the torque. The torque of the motor is used partly in accelerating the car and partly in overcoming the more or less constant resistance of the track. As the speed increases, the current through the motor decreases and its

torque decreases until a balance is reached when the motor torque is just sufficient to maintain the speed of the car. The relationship of current, strength of field, C.E.M.F. and torque is complicated in such a case. In some cases the speed is further increased by shunting part of the current around the field coils or by cutting out part of the coils; in modern practice it is common to connect two motors in series at the start, so that each is subject to only half the line voltage;





A—Efficiency without Gears.
B—Approximate Efficiency with Gears.
C—Safe Time for Load in Service 20° C. rise from 75° C.
D—Speed M. P. H.
E—Electrical HP.
F—Brake HP. with Gears.
G—Tractive Effort.
H—Time to Rise 75° C. from 25° C.

FIG. 1385.—RAILWAY MOTOR AND PERFORMANCE.

then to throw them into multiple, so that each is subjected to the full line pressure for increased speed.

1388. *How can a motor be reversed so as to run in the opposite direction?*

By reversing either the field or the current through the armature, the pull is reversed and consequently the direction of rotation of the armature. If both are changed, the direction of rotation is the same as before. For this reason, it makes no difference which terminal of a motor is positive. The relative connections between the armature and field must be reversed.

CHAPTER XII.

ALTERNATING CURRENTS.

1400. *What is an alternator?*

An alternator is an electrical generator that delivers an alternating-current, as distinguished from a dynamo giving continuous or direct current.

1401. *How is an alternating current different from a continuous or direct current?*

A continuous or direct current is of uniform strength and flows in one direction. An alternating current is continually changing both its strength and direction. Alternating currents, such as used for lighting and power, follow more or less closely what is known as a sine curve. The current begins from zero value and increases rapidly to a maximum value and then decreases to zero, then increases in the other direction to a maximum value and again decreases to zero, somewhat as indicated in the figure in which

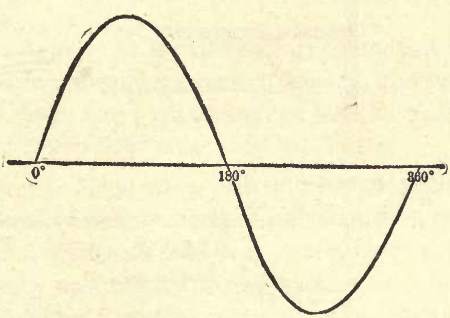


FIG. 1401.—SINE CURVE.

horizontal distances represent time and vertical distances represent the varying values of current or E.M.F. This cycle is repeated from 25 to 130 or more times per second with the machines generally used for lighting and power. (See No. 1498.)

1402. *For what purposes are alternating currents used?*

For heat, light and power distribution, also for medical purposes. In fact, alternating currents are as suitable as continuous for almost

any purpose except electro-plating and other chemical work. For arc lights the alternating current is not always as suitable as con-

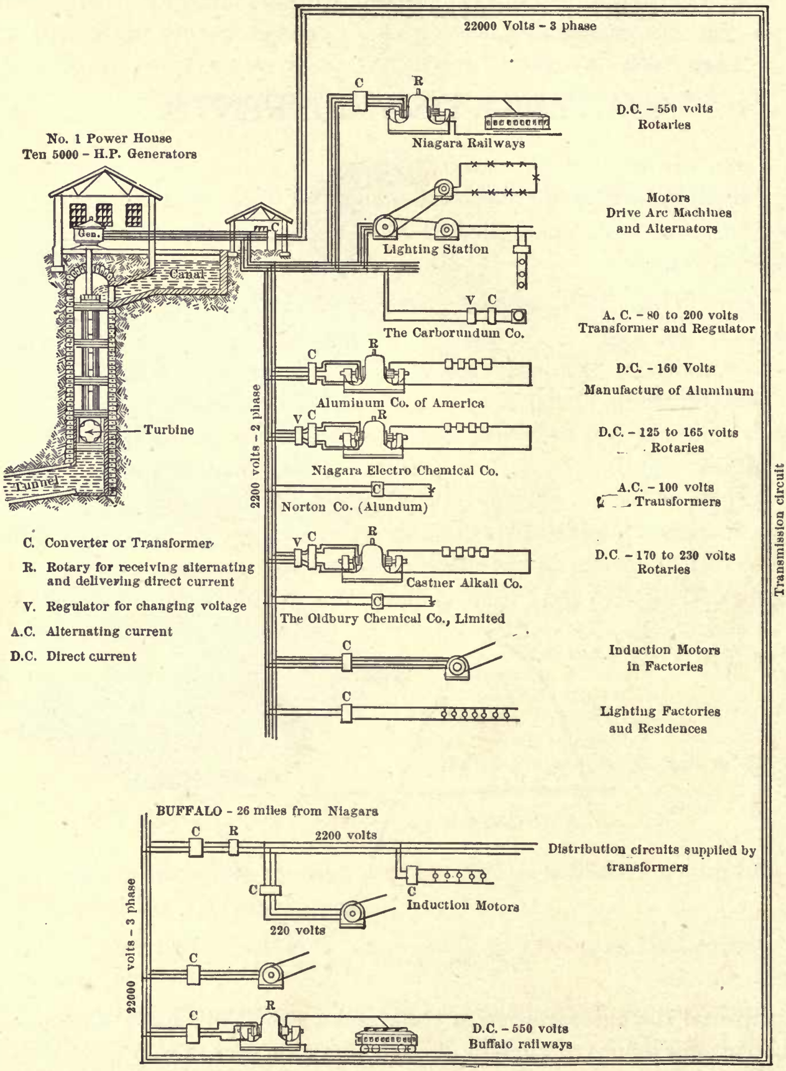


FIG. 1402.— DIAGRAM OF CIRCUITS FROM NIAGARA PLANT.

tinuous current. The diagram shows some of the ways in which alternating current is used from Niagara Falls.

1403. *Has the alternating current any advantages over continuous currents?*

Very heavy currents, such as used for welding, or currents at very high voltages, such as used for long-distance transmission, may be obtained more easily by alternating than by continuous currents.

1404. *How are very heavy currents or very high voltages obtained?*

By means of transformers, sometimes called converters. A transformer consists of a laminated iron core more or less completely surrounded by two coils or sets of coils, one consisting of comparatively few turns of coarse wire, the other of many turns of fine wire as

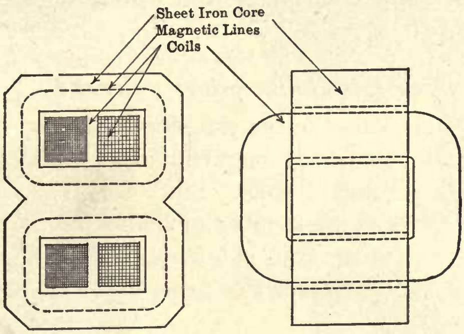


FIG. 1404.—SECTIONS OF TRANSFORMER.

suggested by the figure. If an alternating current of comparatively high voltage and low amperage passes through the fine wire coil, a current of low voltage and high amperage may be obtained from the other. The converse is also true (see No. 1419).

1405. *Explain the elementary principles of the transformer.*

The fundamental principle of the transformer is practically the same as that of a dynamo (see Nos. 1110 to 1114), namely, an E.M.F. is set up by any change in the number of lines of force enclosed by, or threading through, a circuit. The alternating current through one coil causes the iron core to be magnetized, demagnetized and remagnetized in the opposite direction, corresponding to every cycle in the magnetizing current. This changing magnetization induces corresponding E.M.F's in every coil surrounding the iron core, the E.M.F. in each coil being proportional to the rate of change of magnetization and also to the number of turns of wire in the coil. There is thus an induced E.M.F. in the magnetizing coil as well as in the other. In the case of the magnetizing coil the induced E.M.F. is nearly equal to the E.M.F. that causes the magnetizing current,

and is almost directly opposed to it, being known as a counter E.M.F. or C.E.M.F. Since the induced E.M.F. is proportional to the number of turns of wire about the iron cores, it follows that the E.M.F's or voltages in the two coils have the same ratios as the number of turns in their respective coils. For example, if one coil has ninety turns, while the other has only nine, the voltage in the first coil is ten times that in the second. By similar reasoning it may be shown, as experience proves, that the current bears the inverse of the same ratio. For example, if one coil carries 1 amp. at 100 volts, the other would give about 10 amps. at 10 volts, the product of amperes by volts in both coils being nearly equal. As a matter of fact there is a loss, which may vary from 1 to as high as 15 per cent.

1406. *In a transformer, why does the secondary E.M.F. bear a definite ratio to the E.M.F. in the primary circuit?*

Assuming that the losses in the transformer are so small as to be negligible, the same number of magnetic lines of force pass through both primary and secondary coils. Since the E.M.F's in the two coils are proportional to the number of lines of force multiplied by the number of turns in the coil, it follows that the E.M.F's are directly proportional to the number of turns in the two coils.

1407. *How can the voltage of the secondary circuit be changed without changing the primary voltage?*

In a transformer with fixed voltage and number of turns in the primary circuit, the secondary voltage is proportional to the number of turns in series in the secondary coil (see Nos. 1405 and 1406), and to the effective magnetic flux. The secondary voltage may be changed by varying the number of turns in series in the secondary circuit (see Nos. 1410 and 1472), or by varying the effective flux through the secondary (see Nos. 1425 and 1426).

1408. *Why do some transformers have more than four terminals?*

Manufacturers commonly wind transformers with the primary and secondary each in two coils or sections. The two primary coils are connected in series when intended for use on a circuit of about 2200 volts, and are connected in multiple when intended for use on circuits of about 1100 volts. In order to avoid danger from improper connections, the primary coils are often connected inside the case for 1100 or 2200 volts, as may be ordered, and only two terminals for the primary coils come through the outside case. The four terminals of the secondary coils commonly come outside and may be coupled

in series or multiple, according to whether the secondary pressure is to be 110 or 55 volts, or, in later practice, 220 or 110 volts.

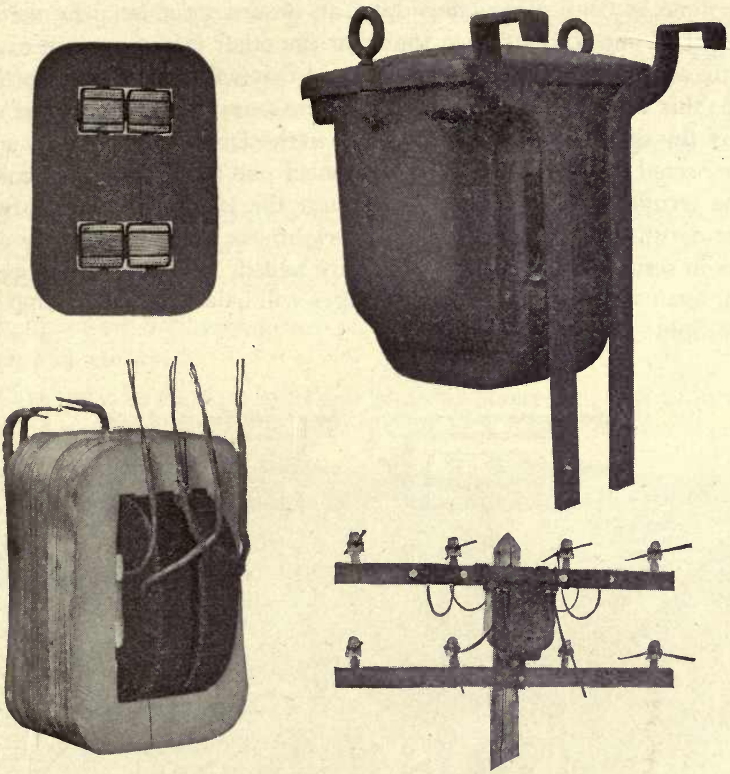


FIG. 1408.—SHELL-TYPE TRANSFORMER.

1409. *How can one tell which terminals are primary and which are secondary?*

The wire in the high-voltage coils is always smaller than that in the low-voltage coils, because it is required to carry less current. Usually the wires coming through the outside case are much larger than the wires in the coils, because of their greater liability to damage in handling. Thus the outside wires are not the same size as those inside, but, as a rule, larger wires are used for the low-voltage coils than for the others.

1410. *How can one tell which terminals of the secondary coils are to be connected together in order to place the coils in series?*

The manufacturers generally send a diagram with the trans-

former, such as that illustrated, showing which terminals are to be connected. If no diagram is available, connect the primary terminals to the line and find out which terminals go with each coil. This can be done by connecting one side of an incandescent lamp to one terminal of one coil and then touching the other lamp terminal to one wire after the other until one is found that will make the lamp light up; this wire is the other terminal of the same coil. In the same way test the other two terminals to see if the lamp will light up when connected between them. Now connect one terminal of one coil to one terminal of the other and connect the lamp between the other two terminals. If it comes up to brightness it shows that the coils are in series so that their E.M.F's are added. If the coils are working against one another, their voltages will balance and the lamp will not light. See also Fig. 337B.

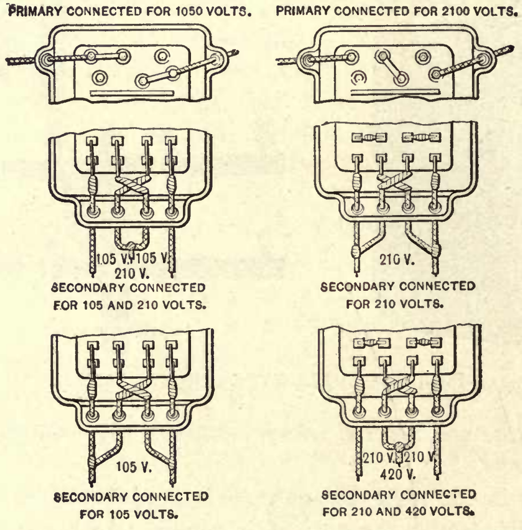


FIG. 1410.—TRANSFORMER CONNECTION DIAGRAM.

1411. *How can one tell the proper way to connect the secondary coils of a transformer in multiple?*

Find the terminals of each coil as shown above (No. 1410) and connect one terminal of one coil to one terminal of the other. Connect the lamp between the outer terminals. If the lamp does not light up with such connection, while it does light up when connected across either coil alone, the outer terminals may be connected safely.

1412. *Is there any harm in improperly connecting the coils in multiple?*

If one coil is connected "upside down" to the other coil, the two are on a short-circuit with both E.M.F's in the same direction sending current through the coils. The result is that both coils will be burnt out if the current in the primary coil is not immediately cut off by the fuse or otherwise.

1413. *Can the secondaries of two transformers be safely connected in series?*

There is no danger in such connection. Care must be taken to connect the right terminals so that the E.M.F's of the two secondaries assist rather than neutralize one another.

1414. *Can the secondaries of two transformers be safely connected in multiple?*

Care must be taken to get them properly connected, just as in the case of coupling the two secondary coils of a single transformer, as

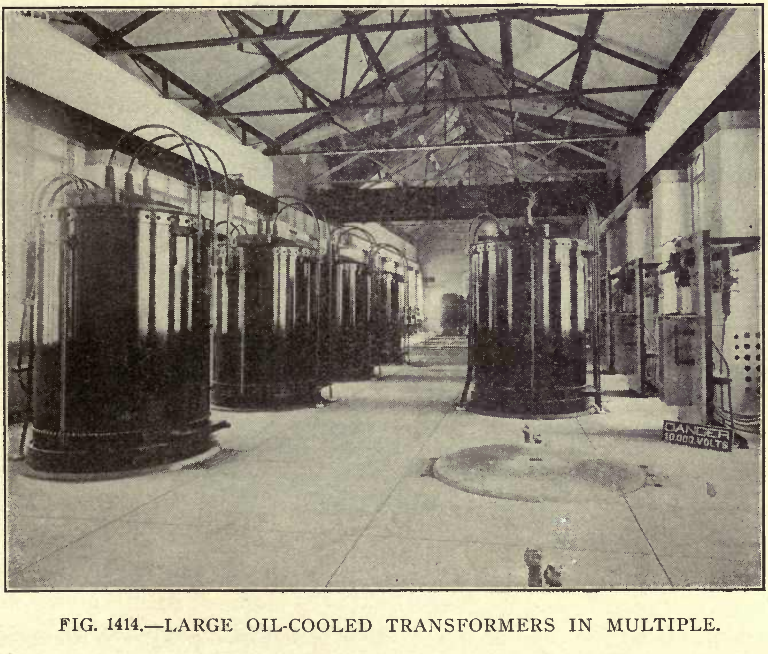


FIG. 1414.—LARGE OIL-COOLED TRANSFORMERS IN MULTIPLE.

considered in No. 1412. The E.M.F's may be tested in the same manner as there outlined. Care must be taken that the secondaries give equal E.M.F's.

1415. *Will the load be properly divided if two transformers have their secondaries connected in multiple?*

It will if the two transformers have similar regulation; that is, if the voltage of each drops off the same number of volts at half load or at full load.

1416. *For what changes of voltage are transformers commonly made?*

The standard practice is to wind transformers for a ratio of some multiple of five. Since both high and low tension windings are usually wound in several sections, they may be connected in series or

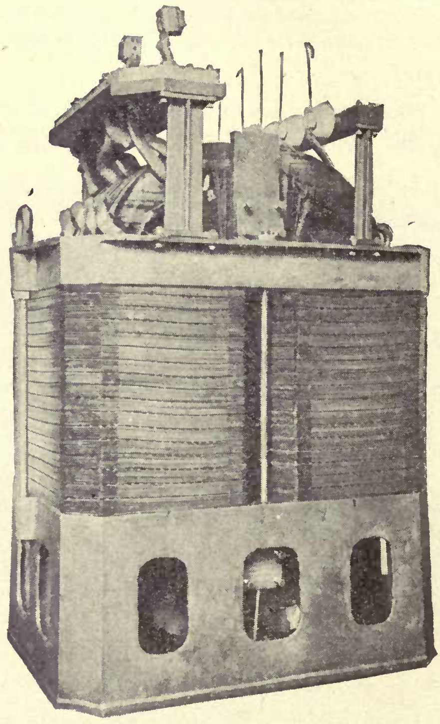


FIG. 1416.—OIL-COOLED TRANSFORMER WITH CASE REMOVED.

in multiple to give two or more ratios (see Fig. 1410). With series connection, "taps" are sometimes brought out from intermediate points, so that two or more voltages may be had simultaneously. For general distribution it is common to have the secondaries give 110 or 220 volts, the primaries being supplied 1100, 2200 or 4400

volts. For transmission lines the generators are wound for 1100 to 6600 volts, the transformers stepping up to from 6600 to 88,000 volts, depending on the distance. These are nominal voltages, since the generator pressure must be sufficiently high to care for the various drops in the lines and transformers.

1417. *What are the sizes of ordinary transformers?*

They range in size from instrument transformers about 6 inches square, taking 25 to 50 watts, to the 7500 kilowatt transformers at Duluth which are 14 feet 10 inches high, 14 feet long and 5 feet 10 inches thick and weighing 171,000 pounds. Ordinary transformers for light and power run from 0.6 to 2000 kilowatts capacity.

1418. *What is meant by "step-up" and "step-down" transformers?*

A step-up transformer is one used for changing the voltage from low to high. A step-down transformer changes the voltage from high to low. There is no difference between the two transformers except in their use.

1419. *How can the same transformer be used either to raise or to lower the secondary voltage?*

The ratio between the voltages of the two coils depends upon the ratio between the number of turns of wire on the two coils. Since both coils surround the same core it follows from the elementary principles laid down before (see No. 1405) that if either coil is connected to a suitable source of supply it will magnetize the core and induce E.M.F. in the other coil. The secondary voltage will be higher or lower than the primary, according to the ratio of the turns of wire in the two coils.

1420. *What prevents an enormous current from passing through the primary coil and burning it out?*

The current is opposed by the C.E.M.F. mentioned above in No. 1405. The small alternating current that passes through the primary coil magnetizes the iron core, first in one direction and then in the other. This rapid magnetization and demagnetization means that the number of magnetic lines of force threading through the iron core inside of the coils is continually changing. Looked at from a slightly different standpoint, it means that lines of magnetic force are continually crossing the coils, or that the coils are continually cutting the lines of force. The result is the same viewed from either standpoint, the changing magnetization of the iron core causing E.M.F's in the coils surrounding the iron. The E.M.F's thus induced in the secondary coil cause current to flow in the secondary cir-

cuit. Likewise, the E.M.F's similarly induced in the primary coil tend to send current through the primary circuit in opposition to the original current. Thus, the E.M.F. induced in the primary coil acts as a C.E.M.F. opposing the impressed E.M.F. or voltage on the primary circuit, and so holding back the current.

1421. *Does the primary coil of a transformer always take the same current, or does the current vary according to the current taken from the secondary?*

The current through the primary is almost exactly proportional to that through the secondary. For example, a 50-light or 2500-watt transformer for reducing from 1000 to 100 volts takes about one-fourth of an ampere (0.23) when the secondary circuit is open; this increases to about 3 amps. when the secondary circuit supplies forty lamps.

1422. *Does the resistance of the primary circuit change, so as to let more current pass when the secondary gives more current?*

No. The resistance of the primary circuit remains constant. Ohm's law, in its simple form, does not always hold true for alternating currents. For instance, the primary circuit of the transformer just mentioned has a resistance of not quite 3 ohms. One might expect that when such a resistance was connected across a 1000-volt circuit, more than 300 amps. would pass, unless something happened to open the circuit. As a matter of fact, less than one-fourth of 1 amp. flows through the primary of this transformer, if the secondary circuit is open so that it delivers no current.

1423. *How does the current taken by the primary increase when the secondary current increases?*

This matter is somewhat complicated, but may be explained in an elementary, although incomplete, way as follows: Since the induced E.M.F's in the coils are in the opposite direction to the E.M.F. sending current through the primary coil, it follows that the current in the secondary circuit is also in the opposite direction to that in the primary. The result is that the secondary current tends to magnetize the iron core in a direction opposite that of the primary current. This opposing magnetizing force would weaken the resultant magnetization and so reduce the E.M.F's in the two coils. But the reduction in the C.E.M.F. in the primary coil allows more current to pass through the primary coil and so to bring up the voltages in both coils to nearly the same values they had before. In practice it is found that this complex action goes on regularly, so that the current through the primary increases in almost exact pro-

portion to that in the secondary. The more complete theory of this reaction is complicated by the fact that the E.M.F's and currents in the two circuits reach their corresponding maximum values at different times, the primary current always being more or less behind the primary E.M.F.

1424. *How can this be explained more briefly?*

When current is taken from the secondary, this current sets up lines of force opposing those of the primary, and the lines thus "killed" are supplied by more current flowing into the primary. Aside from this explanation, from the law of conservation of energy, the primary energy must equal the secondary energy (leaving aside losses) ; and since the two voltages are assumed to remain constant, the primary and secondary currents must increase or decrease together.

1425. *What are series transformers?*

Series transformers, sometimes called " current transformers " or " safety coils," are used on high potential circuits for obtaining current proportional to the main current but at low potential. They are made for current ratios of from 1:1 to 1:200. At switchboards they are used for insulating ammeters, current coils of wattmeters and for relay coils of automatic circuit breakers (see No. 422). In composite alternators they are used for obtaining commutating current proportional to that in one or all of the phases (see Nos. 1468-1470). They are used for operating 10 or 12 ampere flaming arcs from a 4, 6.6 or 7.5 ampere circuit (see No. 485). They are sometimes used for operating indoor series lamps without carrying high tension lines into buildings. Care should be taken not to open the secondary of a constant-current transformer, as the pressure may rise dangerously high because of the increase in magnetic flux due to the absence of the countermagnetizing secondary current (see Nos. 1405, 1423). The safe plan is to short-circuit the secondary, in case it is necessary to make changes while power is on. The current transformer is based on the same principles as the constant potential transformer, differing only in details of design and method of use. (See also No. 1472.)

1426. *Can transformers be made to give secondary current of constant strength when the primary is connected to a constant-potential circuit?*

Several companies make transformers that give approximately constant current within wide ranges of voltage when the primary

is supplied at constant potential. This is usually accomplished by designing the transformer so that there will be considerable magnetic leakage. As stated before (No. 1423), the current in the secondary

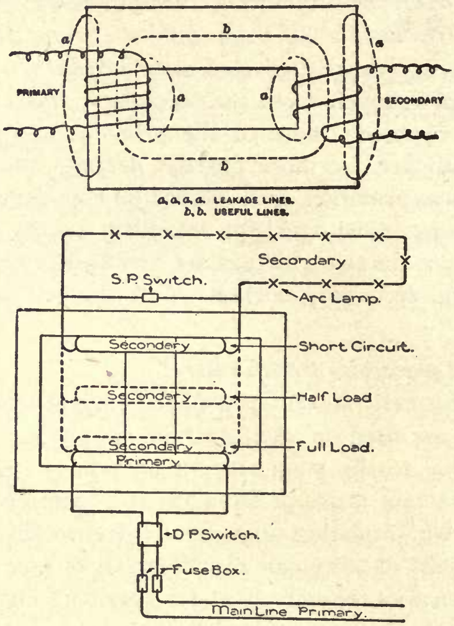


FIG. 1426A.—OPERATION OF CONSTANT-CURRENT TRANSFORMER.

coil has a magnetizing effect in the opposite direction to that of the primary current. This counter magnetomotive force makes it more difficult for the magnetic field from the primary to pass through the secondary, and so more of the magnetic lines of force leak across without threading through the secondary coil, as suggested in the figure. Since the E.M.F. in the secondary coil is proportional to the number of magnetic lines of force enclosed by it, it follows that the greater the amount of leakage the less will be the secondary E.M.F. It follows further that if the secondary current increases, the leakage will also increase, thereby diminishing the secondary E.M.F. and in turn diminishing the secondary current. By suitably designing the magnetic circuit, the leakage field will increase in such proportion to the increase of secondary current that the secondary current will remain nearly constant. In a constant-current transformer of the General Electric Company the amount of magnetic leakage is varied by an automatic adjustment of the relative positions of the primary and secondary coils. Several manufacturers obtain nearly constant

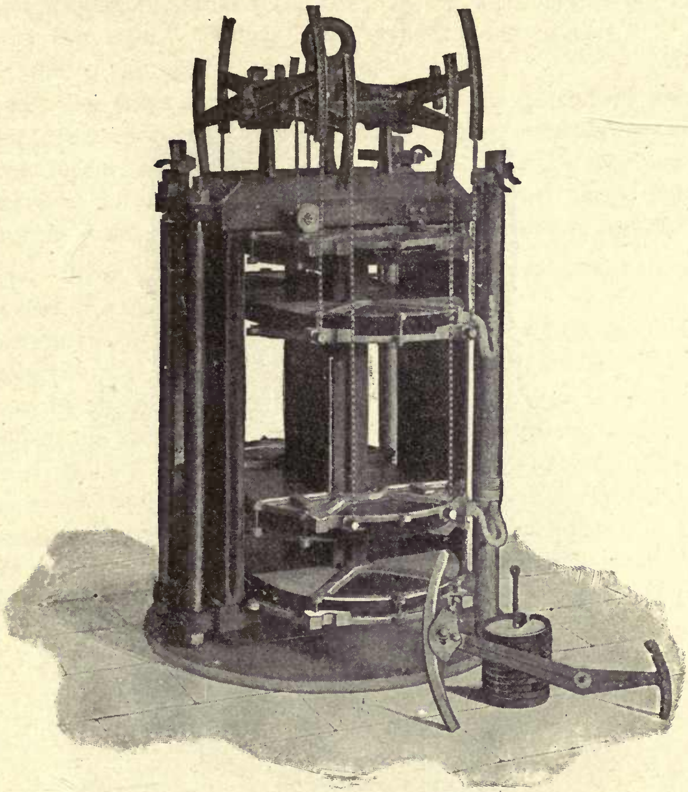


FIG. 1426B.—CONSTANT-CURRENT, ARC LIGHT TRANSFORMER.

current from constant-potential circuits by inserting a choke coil with variable impedance. (See Nos. 1473 to 1477.)

1427. *How do alternators differ from direct-current generators?*

Excepting "unipolar" machines, which have not proved commercially successful, all direct-current machines (dynamos or motors) require commutators for rectifying the current (Nos. 1114-1117); the need of adjusting the brushes requires the armature to be the moving part. The alternator has more field poles, and either the armature or field may revolve (see 1459-1461). Ordinarily, current is conducted to and from the rotor through brushes bearing on continuous rings called collecting rings or slip rings. (See 1428 and 1431.)

1428. *What is meant by rotor and stator?*

Since an alternating-current generator or motor may have either the armature or the field rotate, the revolving part is commonly called the rotor, and the stationary part the stator.

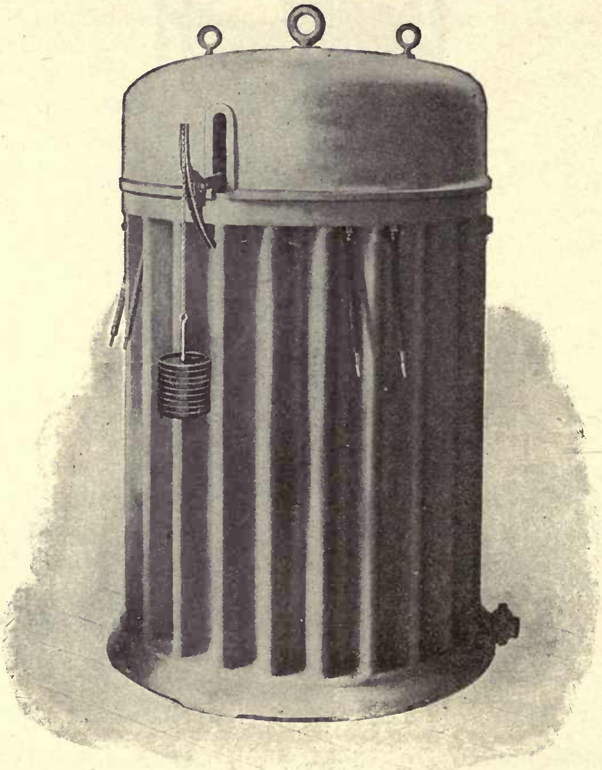


FIG. 1426B.—CONSTANT-CURRENT, ARC LIGHT TRANSFORMER.

1429. *Would a direct-current dynamo give an alternating current if collecting rings were substituted for the commutator?*

It would if means were provided for keeping up the magnetic field. But this would not be the most economical winding for an alternator, and a machine built for alternating currents would be wound differently from a direct-current machine. Machines are made having a commutator and also a set of collecting rings. When these machines are driven from an outside source of power they are called "double-current generators." The same machine may be used to change direct current into alternating current, or *vice versa,* one kind of current entering at one set of terminals and the other kind of

current leaving the other terminals. In the latter case it is called a "rotary converter," "rotary" or "synchronous converter." (See Nos. 1468 to 1471 and 1510 to 1519.)

1430. *For what purposes are double-current generators used?*

They are used in central stations which deliver alternating current to some feeders and direct current to others, the same machine supplying two different services, according to requirements, thus reducing the number and capacity of machines otherwise necessary.

1431. *How does the winding of an alternator armature differ from that of a direct-current machine?*

In modern direct-current machines, all the coils on an armature are exact duplicates. Alternating-current generators have two general styles of winding, either all coils alike or else several forms of coil in the same machine. By varying the spacing and connections of the coils, all of their E.M.F's may be combined into one so as to give a single-phase current, or so as to give two-phase or three-phase currents (see Nos. 1437 to 1451 and 1459 to 1461). When each circuit has one coil per pole, the winding is said to be "uni-tooth;" when there are two or more coils per pole per phase,

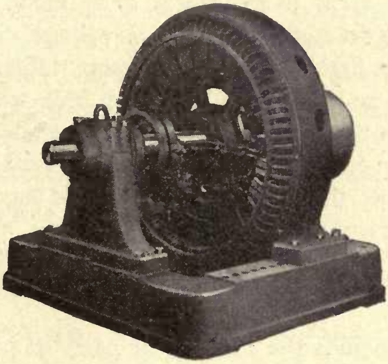


FIG. 1431.—ALTERNATOR WITH REVOLVING FIELD AND WITH GROUP WINDINGS.

the winding is said to be "multi-tooth," "poly-odontal" or "distributed," such distribution lowering the total E.M.F. somewhat, but lessening the armature magnetic disturbance and tending toward giving a more nearly sinusoidal E.M.F. Alternators with only one coil per pole per phase, especially single-phase machines, are apt to

be noisy and to give trouble from heating in the pole tips on account of the surging of the magnetic field as the wide teeth and slots pass. Most modern alternators have revolving fields.

1432. *How many poles do alternators have?*

Small magneto machines for telephone signals and testing have only two poles. Alternators driven by steam turbines, which run at high speed, have two to eight poles. Other alternators have from six to sixty or more poles. (See No. 1121.)

1433. *Why do alternators have so many poles?*

In order to get high frequency without excessive speed of armature. The alternating currents used practically make from 3000 to 16,800 reversals per minute, or make from 25 to 140 complete cycles per second, the more common modern practice in America being 25 and 60 cycles per second, European practice favoring 25 and 50 cycles.

1434. *What limits the frequency of alternating currents?*

The lower limit is governed by the use made of the current. Unless the frequency is as high as about 40 cycles per second, arc lamps will not burn well and incandescent lights are apt to flicker. High frequencies were used when alternating currents were first introduced in order to allow transformers to be made small and cheap for a given output to compete with low-voltage direct-current systems. But with the high frequency it is more difficult to operate motors satisfactorily, and the difficulties from induction on the circuits increase. Modern practice favors 50 and 60 cycles for general use and 25 for power only. For certain experimental work, frequencies running up into the thousands per second have been used, but these have not yet reached the commercial stage.

1435. *How can the frequency of an alternating current be measured?*

The frequency equals the number of pairs of poles in the alternator multiplied by the number of revolutions per second. For example, a turbo-generator having eight poles and running at 15 revolutions per second gives a frequency of 60 cycles per second.

1436. *How can the number of alternations be determined?*

The number of alternations per minute equals the number of poles multiplied by the number of revolutions per minute. For example, the machine with ten poles running at 1500 r. p. m. gives 15,000 alternations per minute.

1437. *What is a two-phase current?*

By a two-phase current is meant two separate alternating currents which are maintained at a constant difference of phase. These currents are 90 degrees apart, one current being at its maximum value when the other is at its zero value. This is illustrated in the figure, in which the solid curve, *B*, represents one current and the dotted

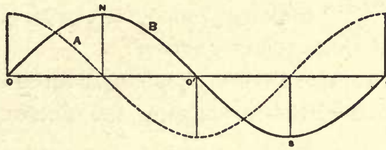


FIG. 1437.—CURRENTS 90 DEGREES APART.

curve, *A*, the other, the value of the current at any instant being represented by its distance above or below the straight horizontal line, the distance from o to o″ representing the time required for a complete cycle. Each current is usually carried on its own circuit independent of the other. "Quarter-phase" is another name for two-phase.

1438. *How are two-phase currents obtained?*

One way is by the use of four collecting rings connected with four points on a direct-current commutator, one pair being connected to points directly under brushes of opposite polarity, the other pair being connected to points midway between these. Another method is to couple the armature shafts of two similar alternator armatures together so that the E.M.F. of one is a maximum at the same instant that the E.M.F. of the other is at zero. The more usual method for commercial work is to use a regular two-phase alternator.

1439. *What is a two-phase alternator?*

A two-phase alternator has two separate windings which are so

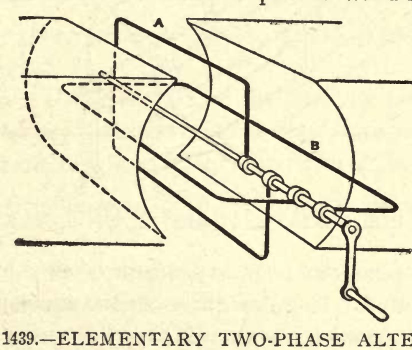


FIG. 1439.—ELEMENTARY TWO-PHASE ALTERNATOR.

arranged that the E.M.F. in one is zero at the instant when the E.M.F. of the other is at a maximum. This is illustrated diagram-

matically in the figure, which represents a two-pole machine with two coils at right angles. In the sketch shown, the coil, *A,* is at the position of zero E.M.F., while coil *B* is in the position of greatest E.M.F. In the actual two-phase alternators there are, of course, more poles and more coils in each circuit, the two sets being arranged so that the coils of one set are between the poles when the others are under them.

1440. *What is a three-phase current?*

A so-called three-phase current consists of three separate currents in three separate circuits, the three being 120 electrical degrees apart,

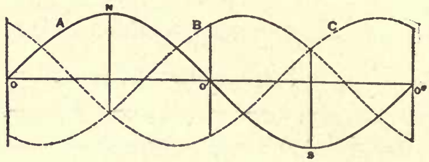


FIG. 1440.—CURRENTS 120 DEGREES APART.

as illustrated in the figure. If the time or distance from o to o″ be considered as divided into 360 degrees, representing an entire circle or cycle, corresponding values of the three currents are 120 degrees apart. See also No. 1453.

1441. *How are three-phase currents obtained?*

By collecting rings coupled to points on a direct-current generator 120 degrees apart, considering the distance from a positive to a negative brush on the commutator as being 180 degrees or one-half cycle.

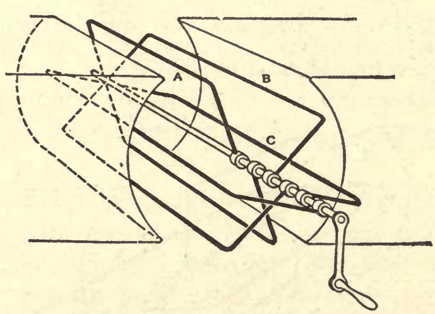


FIG. 1441.—ELEMENTARY THREE-PHASE ALTERNATOR.

Also three single-phase alternator armatures may have their shafts mechanically coupled. Regular three-phase alternators have three distinct armature windings equally spaced; in the actual machine, these are connected at one or three points (see Nos. 1450 and 1451), so as to require only three collecting rings or terminals.

1442. *What are polyphase currents, and for what are they used?* Polyphase and multiphase are names for two or more alternating currents having a fixed phase difference, such as two-phase (quarter-phase), three-phase or six-phase. They are more satisfactory for operating motors, except small ones; power is transmitted cheaper by three-phase than by single-phase or by direct current.

1443. *Is it necessary to have four wires for carrying two-phase currents?*

Four wires are generally used, two for each circuit, as suggested in the figure, in which, for simplicity, the transformers are omitted.

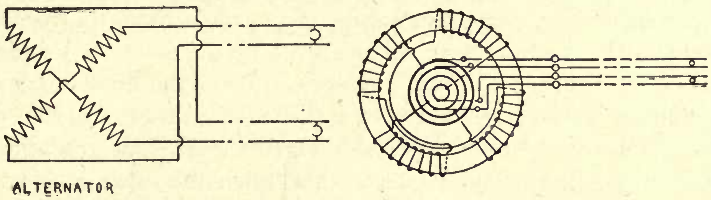


FIG. 1443A.—FOUR-WIRE TWO-PHASE SYSTEM.

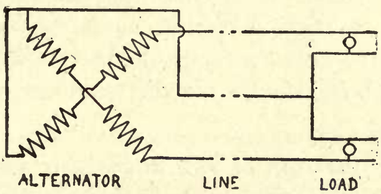


FIG. 1443B.—THREE-WIRE TWO-PHASE SYSTEM.

Sometimes one common wire and two outers are used, as in the direct-current three-wire system, except that in the two-phase system the common wire should be 1.4 larger than the outers.

1444. *In the three-wire two-phase system, is the common wire the same as the others?*

In order to give the same loss on the line, the common wire should be 1.414 times larger than the other wires, because the current in the common wire is the resultant of the two currents in the other wires.

1445. *Is not the current in the common wire equal to the sum of the two currents?*

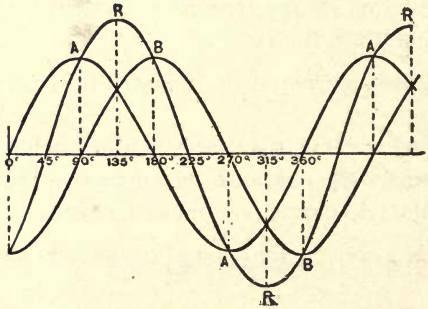
Yes and no. At any instant the current in the common wire equals the sum of the two currents. But an ammeter in the common wire would not indicate as much as the sum of the ammeter readings in the two circuits. For instance, if each circuit was carrying 10 amperes, the common wire would be carrying 14.14 amps.

1446. *Do not the rules of ordinary arithmetic apply to alternating currents?*

They do when rightly applied. Ordinarily, $10 + 10 = 20$, but in this case, $10 + 10 = 14.14$. The same thing is true in many other cases with alternating currents. The difficulty is caused by the fact that the two currents or E.M.F's may have a difference of phase, so that they do not reach corresponding values at the same time. At any particular instant, the current in the common wire is the sum of the two currents at that same instant. But the ammeter does not measure the instantaneous values of the current, it measures the effective current. If the two currents were in the same phase, reaching corresponding maximum values at the same time, the resultant current in the common wire, as measured by the ammeter, would be equal to the sum of the two currents, and, in the above example, the ammeter would show 20 amps. in the common wire. On the other hand, if the two currents were 180 degrees apart, one reaching its maximum positive value at the instant when the other reached its maximum negative value, the two currents in the common wire would exactly neutralize one another, and the ammeter would stand at zero. In this case the two circuits would be practically in series. the current being the same on each side, and the voltage between the two outside wires being double that between either outside wire and the neutral wire.

1447. *What is the sum of two alternating currents 90 degrees apart?*

The way in which the two currents are combined in the common wire to form a resultant less than their sum is illustrated in the



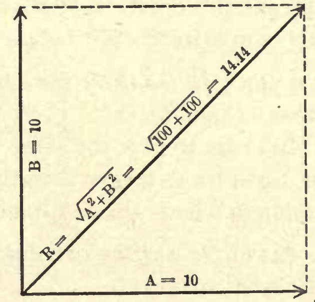


FIG. 1447.—COMPOSITION OF TWO CURRENTS.

figure. Suppose that the sine curve, *A*, represents the current coming into the common wire from one circuit, while *B* represents the other current. The value of the resultant current, *R*, is found at

any instant by adding the values of A and B at that instant. For example, at the instant marked 45 degrees the value of B is negative and exactly equal to the value of A at the same instant, so that the instantaneous sum or the resultant of the two is zero. Again at the point marked 90 degrees, B is at zero, while A is at its positive maximum value, and the sum equals A. A little later, at the point marked 135 degrees, both B and A are positive and the resultant equals their sum at that instant. By following this analysis through the cycle, it is seen that the curve representing the resultant or sum of the simultaneous values is a curve similar to the others, and its mean value bears the same ratio to its maximum value that the mean value of either of the component curves does to its maximum.

1448. *How are two-phase alternator armatures wound?*

The two circuits may be entirely distinct, each having two collecting rings as suggested in Fig. 1443. Or the two circuits may be

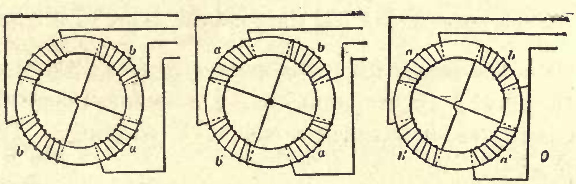


FIG. 1448.—ELEMENTARY TWO-PHASE ARMATURES.

coupled at a common middle point as suggested in the accompanying figure, each circuit having two collecting rings. Or the two circuits may be coupled in the armature so that only three collecting rings are required, as suggested in the third figure.

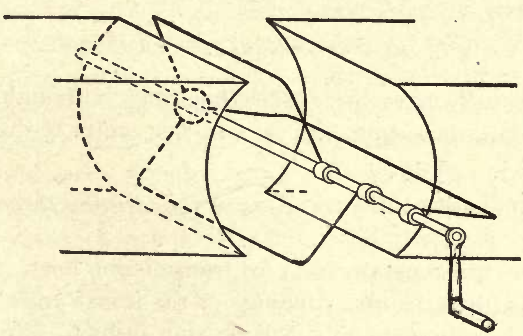


FIG. 1449.—ELEMENTARY THREE-PHASE ALTERNATOR.

1449. *How are three-phase alternator armatures wound?*

There are generally three coils or sets of coils, 120 electrical degrees apart, as in the ideal sketch in the figure. Instead of having

two terminals for each coil or circuit, these are generally connected so that only three or four collecting rings are required.

1450. *What is meant by a mesh-connected three-phase armature?*

When connected so that the three coils form a complete circuit within themselves, as Fig. 1450 indicates, it is said to be a mesh or

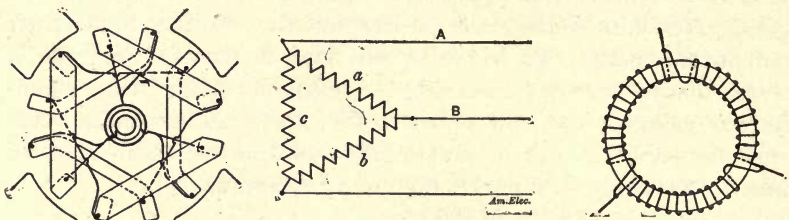


FIG. 1450.—"DELTA" CONNECTED ARMATURES.

triangle winding. Sometimes this is called a "delta" connection, because the Greek letter Delta has the general shape of a triangle.

1451. *What is meant by a star-connected three-phase armature?*

When the three coils are connected at a common central point, as Fig. 1451 indicates, it is called a star or Y winding. Three-phase

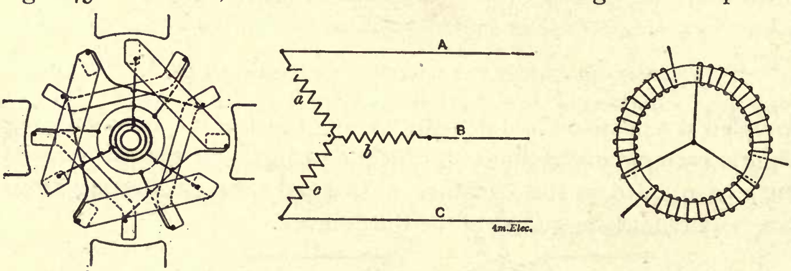


FIG. 1451.—"Y" CONNECTED ARMATURE.

alternators usually have three collecting rings, although there may be a fourth ring connecting with the common center of the star winding.

1452. *How many wires are required for carrying three-phase currents?*

Three wires are generally used for transmission lines. For distributing circuits, the armature windings or the transformer secondaries are frequently connected in "Y" or star fashion, four line wires connecting with the outer terminals and with the center or neutral point. Lamps are then connected between the neutral and an outer. Four-wire systems are less disturbed by unequally balanced loads.

1453. *How can three separate currents be carried on three wires and yet be distinct?*

Each wire practically becomes the return wire for the other two circuits. When all three currents are equal. they may be considered as neutralizing one another at the common meeting point so that no return wire is necessary. This may be understood by examining the

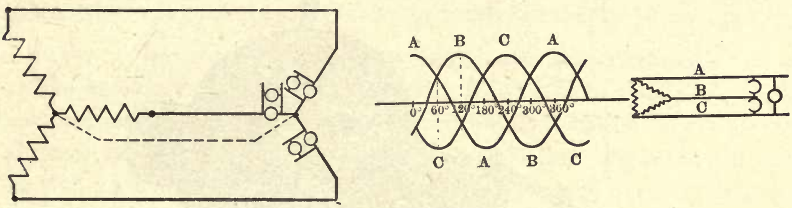


FIG. 1453.—THREE-PHASE CIRCUITS.

figure, in which *A, B* and *C* represent the three currents 120 degrees apart. It may be seen that at any instant, for example, at the point marked 60 degrees, the negative value of *C* just equals the sum of the positive values of *A* and *B*. In the same way, at any other instant the sum of three currents is zero, and therefore no return wire is necessary.

1454. *What sort of current is used for the field coils of alternating-current machines?*

The fields are excited by direct current, except in the case of induction (not inductor) generators and of induction motors.

1455. *Why is it necessary to use direct current in the field coils of alternators?*

The machine will refuse to generate E.M.F. unless the field is continuously excited. If an alternating current should be sent through the field coils, the magnetic field would follow the variations of the current, a given pole being a strong north pole at one instant, then weakening to zero and becoming a south pole. Since a magnetic field always tends to oppose changes rather than to make them, the field would have no tendency to reverse of itself, and therefore the machine would not pick up. It would be like trying to make a direct current dynamo pick up when the field connections were reversed.

1456. *How is the exciting current obtained?*

In some early alternators a special set of coils was wound on the alternator armature and connected with a commutator from which a direct current was obtained for the field coils. On account of the difficulty of insulating and repairing this special winding, which was usually placed under the alternating-current armature coils, this method was abandoned. Practically all the alternators in use at

present take their field-exciting current from a small direct-current machine called an exciter.

1457. *How is the exciter generally driven?*

The exciter is a direct-current generator driven from the alternator shaft or from some other source of power. Frequently it is mounted

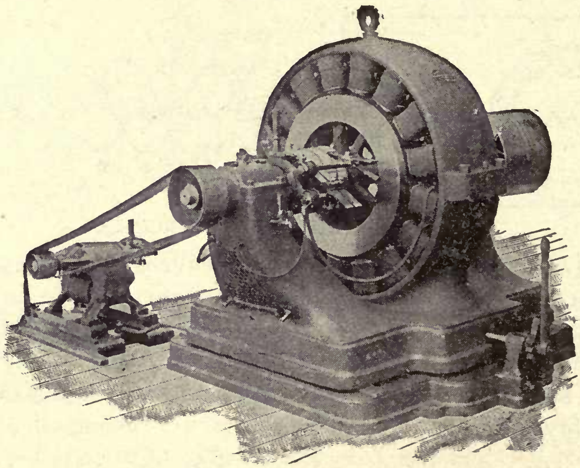


FIG. 1457.—ALTERNATOR AND BELTED EXCITER.

on the alternator frame, being driven by belt or gearing or having its armature mounted on the alternator shaft. (See Fig. 1137.)

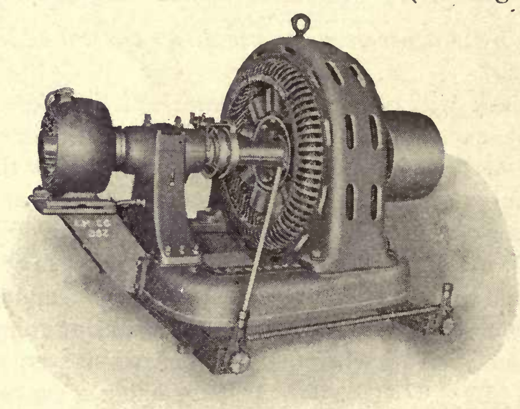


FIG. 1458.—ALTERNATOR WITH DIRECT-CONNECTED EXCITER.

1458. *Why is the exciter armature sometimes mounted on the same shaft with the alternator?*

The early practice was to drive alternators by belts and to belt the

exciter from the alternator, the exciter making more revolutions per second, the high speed keeping down its cost. Trouble was found in keeping the proper tension on the exciter belt, especially when adjusting the main belt. Most of the difficulties were eliminated when the exciter was mounted on the alternator, especially when directly driven. When the alternator is large enough to be directly connected to the source of power the exciter is generally driven by its own power.

1459. *Why are alternators generally made with revolving fields?*
The armature windings can be better insulated, having more space and not being subject to so severe mechanical strains This allows alternators to be wound for higher voltages, thus obviating the use of step-up transformers in some cases. The only moving contacts

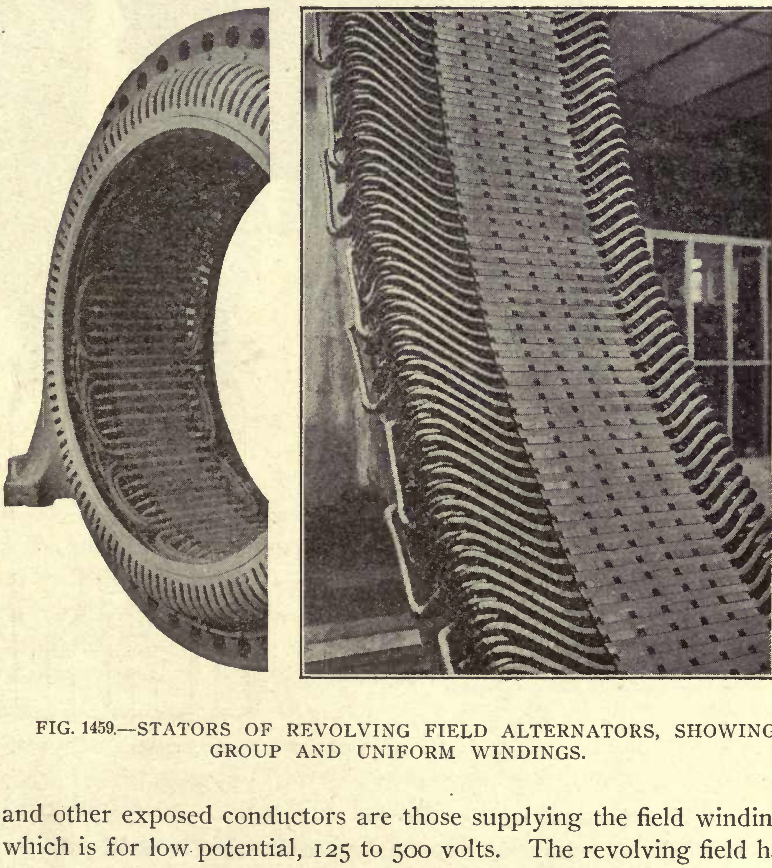


FIG. 1459.—STATORS OF REVOLVING FIELD ALTERNATORS, SHOWING GROUP AND UNIFORM WINDINGS.

and other exposed conductors are those supplying the field winding, which is for low potential, 125 to 500 volts. The revolving field has greater flywheel effect, which is sometimes desirable.

1460. *What sort of machines have both field and armature stationary?*

The so-called inductor machines have no moving wire whatever. Examples are the Mordey (English), Stanley and Warren alterna-

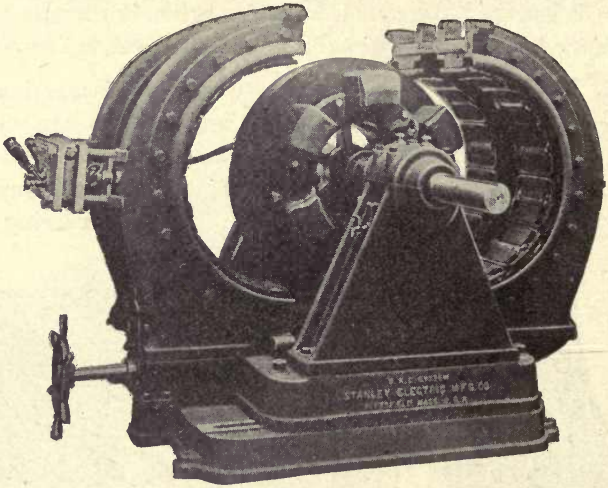


FIG. 1460A.—INDUCTOR ALTERNATOR (ARMATURE OPENED).

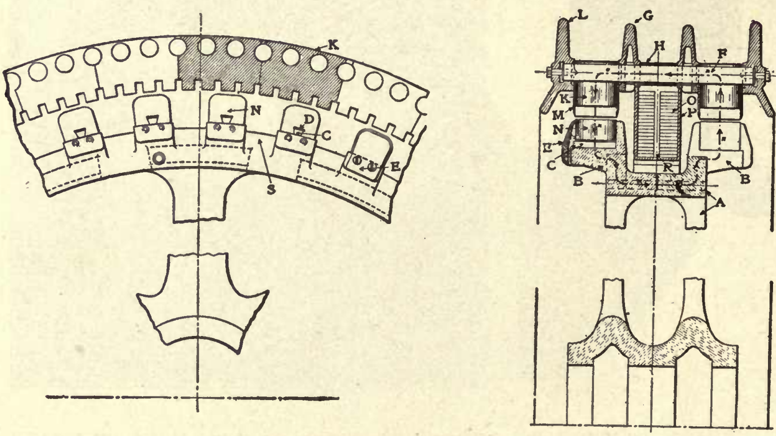


FIG. 1460B.—INDUCTOR ALTERNATOR (SECTIONS).

tors. The figures show the Stanley ("S.K.C." or Stanley-Kelly-Chesney") inductor alternator as made by the General Electric Company. The stationary field coil *o* sends magnetic flux through

the path indicated by dash-dotted line, passing through the steel magnet bars F and the two slotted laminated armature cores of the stator, and through the laminated steel poles N and cast-steel spider S of the revolving element or "inductor." The armature windings consist of two sets or crowns of coils, each crown including two (or three for three-phase) interspaced series of coils, one coil per phase per pole.

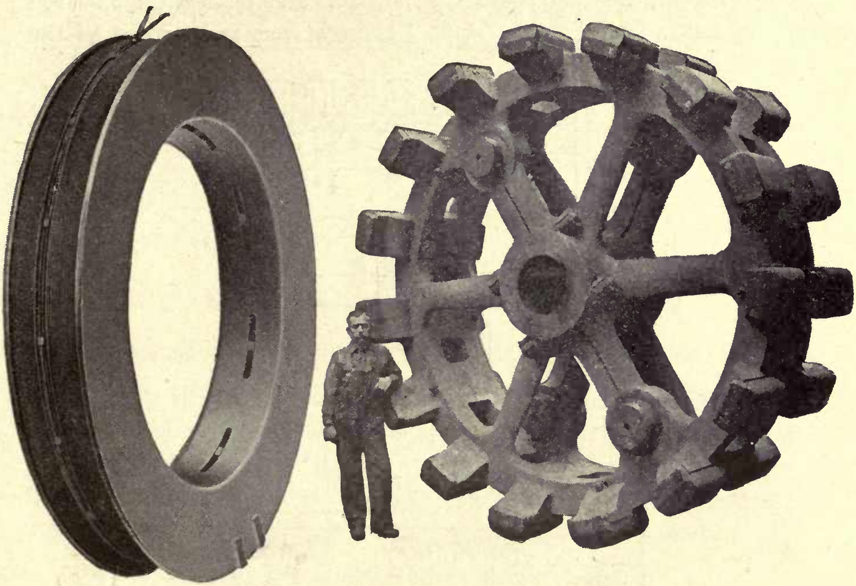


FIG. 1460c.—INDUCTOR ALTERNATOR FIELD COIL AND ROTOR.

1461. *How is the E.M.F. induced in inductor machines?*

The magnetic field always passes through a given armature coil in the same direction, but the strength of the field through the coil varies according to the position of the moving projecting pole. This causes a regular periodic rise and fall in the magnetic flux through each coil. The two sets of coils in each crown are interspersed so that the magnetic field through one set is strongest when the field through the other set is weakest. The E.M.F's in the two sets are therefore 90 degrees apart, or "in quadrature." In the three-phase machines, the space is divided so as to hold three equally spaced coils per pole.

1462. *How may the voltage of an alternator be regulated?*

By varying the rate of change of the number of lines of force pass-

ing through the armature coils. The general principles are similar to those for the regulation of direct-current machines, for which see Nos. 1158 to 1170. The methods applicable to alternators are variation of the number of active armature wires and of the field strength, speed variation being barred by motors requiring constant frequency.

1463. *How can the number of active wires be changed in the armature of an alternator?*

On revolving field alternators, it is practicable to arrange a switch or "regulator head" with "taps" brought out from some of the

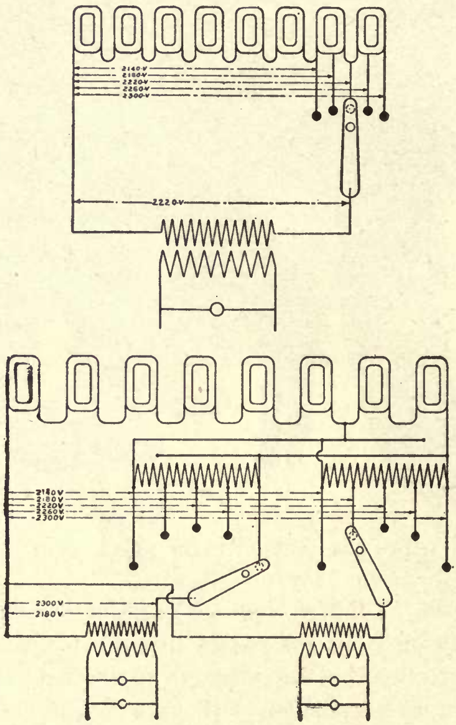


FIG. 1463.—METHODS OF GETTING SEVERAL VOLTAGES FROM ONE ALTERNATOR.

end coils, or from different points in the winding of a single-coil transformer shunted around one or more armature coils.

1464. *In what ways may the field strength of an alternator be changed?*

By varying the current through the field coils. The other methods sometimes used with continuous-current machines, namely, of varying the number of turns in the field coils or of changing the reluctance of the magnetic circuit, are not generally applicable because of the large number of poles in the alternator field.

1465. *In what ways may the field current of an alternator be changed?*

By varying the voltage of the exciter dynamo, by varying the resistance in the alternator field circuit and also, if the machine is of the composite type, by varying the current through the rectifier and series coils.

1466. *How is the voltage of the exciter varied?*

It is common to use a shunt dynamo for the exciter and to control its voltage by a rheostat in the field circuit. A second rheostat in the field circuit of the alternator allows closer regulation, and also allows independent regulation of two or more alternators supplied from the same exciter. Large stations frequently have several exciters feeding into special busbars, from which the alternators are supplied, each having its own field rheostat and field switch.

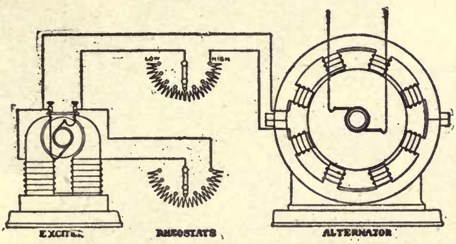


FIG. 1466.—ALTERNATOR WITH EXCITER AND RHEOSTATS.

1467. *How was the Heisler alternator regulated?*

In the Heisler machines formerly used for series incandescent lighting, the exciter was a series dynamo, the voltage of the exciter and, consequently, the current through the alternator field being regulated entirely by shifting the brushes, a method common with arc-light dynamos. A similar method was used with some European alternators. Since the Heisler machine was a two-phaser, supplying two series circuits in which it was necessary to maintain the current of constant average value, an auxiliary regulator was necessary to govern each current independently. This consisted of an adjustable rheostat in each circuit, with an ingenious automatic device that cut resistance in or out as might be necessary. There was a further auxiliary attachment that kept the exciter brushes in such a position that the E.M.F. of the alternator was just sufficient to keep the current of the proper strength in the longest circuit. This machine had the reputation of being about the only alternator of the older generation that paid dividends to the station manager, a result due to the absence of the imperfect transformers of early days.

1468. *What is an alternator of the composite type?*

A composite alternator is similar to a compound-wound, continuous dynamo in that it has two field windings. In addition to the regular field coils which carry the main magnetizing current from the

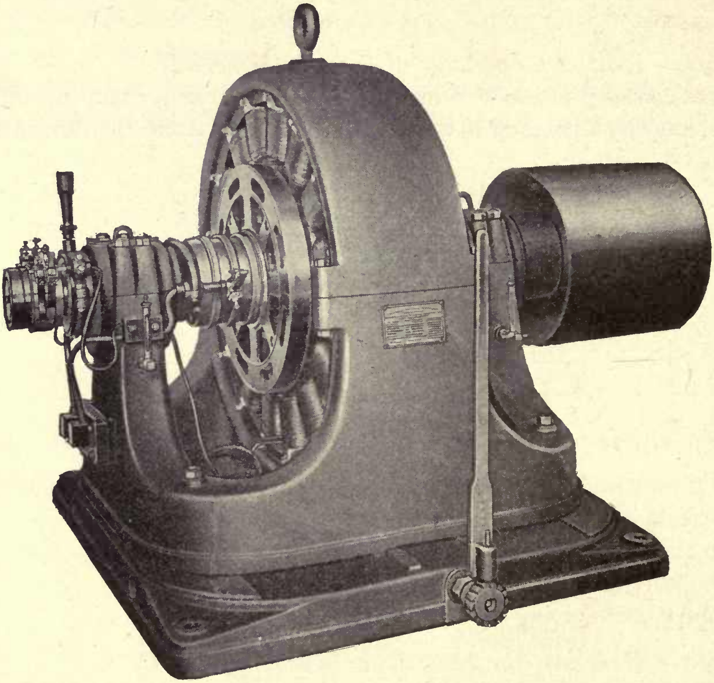


FIG. 1468.—COMPOSITE ALTERNATOR.

exciter, there is a second winding upon two or upon all of the pole pieces, carrying a rectified current from the alternator which strengthens the field to balance the losses in the machine, and also, if so desired, the losses on the line.

1469. *How is the alternating current rectified?*

The alternator shaft carries a commutator having as many segments as there are poles in the field. Alternate bars are coupled and brushes are adjusted so that both change simultaneously from one set of bars to the other. When the commutator is connected to the armature circuit the brushes may be adjusted so as to change from one set of bars to the other at the same instant when the armature current changes direction. The brushes will then take off a current that pulses, but always flows in the same direction.

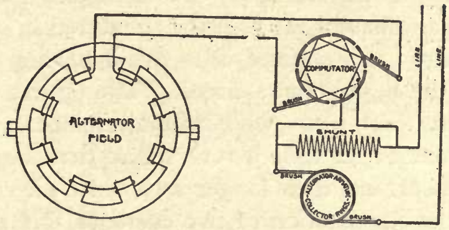


FIG. 1469.—CIRCUITS OF COMPOSITE ALTERNATOR.

1470. *How is the rectifier connected into the circuit?*

Sometimes it is connected directly in series with the armature, one set of commutator segments being connected directly to one end of the armature winding, while the other set of bars is connected

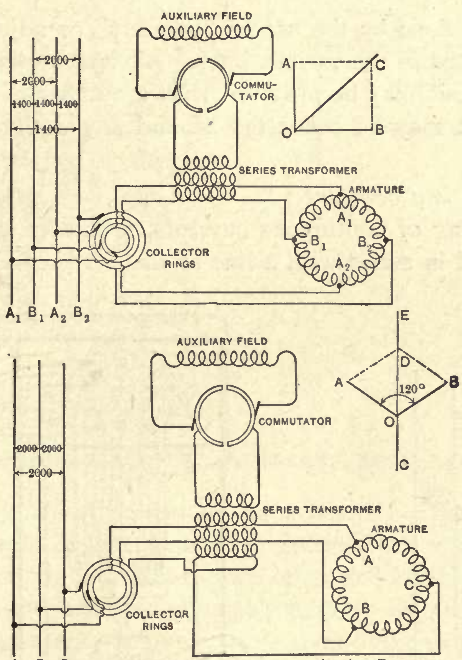


FIG. 1470.—CIRCUITS OF POLYPHASE COMPOSITE ALTERNATORS.

to the outside circuit through a collecting ring and brush. Sometimes an adjustable shunt is connected around the commutator, as suggested in Fig. 1469, so that only part of the current is rectified. In other cases, the whole current is rectified, but only part goes through the field coils while the remainder goes through an adjustable shunt. Sometimes the current for the com-

mutator is taken from the secondary of a transformer attached to the armature spider and having its primary connected in series with the armature windings; this scheme is to avoid having the field coils connected with the high-voltage circuit. The figures show the circuits for two and three-phase composite alternators. In the three-phase machine, one of the coils is reversed so that the instantaneous sum of the three currents is no longer zero, since the currents are 60 degrees apart; the combination of two currents, *OA* and *OB,* gives a resultant, *OD,* which, combining with the third current, *OC,* gives the final resultant, *OE*, which is the effective current in the transformer, inducing the current which goes to the commutator and thence to the auxiliary field coils.

1471. *Can several circuits be supplied at different voltages by the same alternator?*

This may be done by the use of "boosters" or adjustable transformers connected in the various lines. Alternators having stationary armature coils may be provided with a number of terminals so that any circuit may be connected around any desired number of armature coils.

1472. *What is a booster?*

When speaking of continuous currents, a booster is a small dynamo connected in series with a line so that its E.M.F. is added to

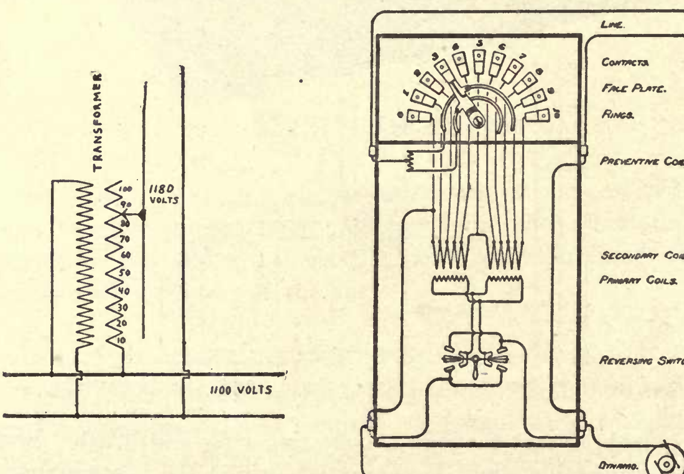


FIG. 1472A.—DIAGRAMS OF BOOSTER TRANSFORMER.

the voltage across the terminals. When speaking of alternating currents, the booster is a special transformer whose secondary is con-

nected in the line to raise or lower the voltage. The secondary coil has several terminals for adjustment and the primary coil is connected through a reversing switch so that the secondary will either raise or lower the voltage on the line. Diagrams of the Westinghouse booster are given in the figures. The General Electric Com-

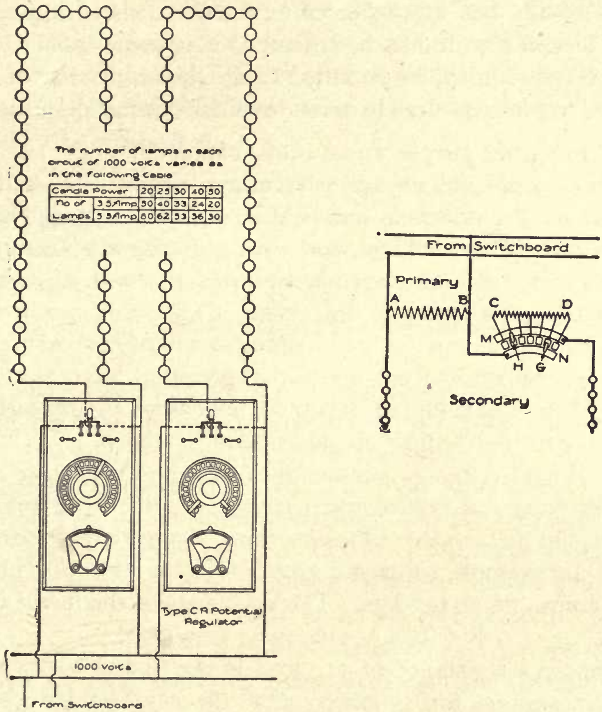


FIG. 1472B.—SERIES INCANDESCENT REGULATOR.

pany has two kinds of booster or compensator. That intended for handling currents of considerable magnitude has a primary and a secondary coil at right angles to each other and enclosing a common laminated iron core with an adjustable center. By shifting the position of the central core, the inductive relation of the two coils is modified so that the voltage induced in the secondary is varied in amount and direction. For smaller currents, such as 3.5 or 5.5 amperes, used for operating incandescent street lamps in series, they used a compensator similar to that shown in the first figure, except that instead of reversing the primary to raise or lower the voltage, the secondary terminals are arranged with two sliding contacts, *H* and *G*, which can move relatively past one another so as to raise or lower the voltage any desired amount; when *H* and *G* are on the same

block, the voltage on the line is the same as that on the switchboard. Their more recent practice is to use constant-current transformers similar to those used for series arc lighting (see No. 1426).

1473. *What is a choke coil?*

A choke coil consists of a coil of wire surrounding a laminated iron core. It usually has a number of terminals so that the number of turns of wire in circuit may be adjusted, or in some cases part or all of the iron core is movable so as to change the inductance of the circuit. The coil is connected in series with any circuit desired.

1474. *For what purposes is a choke coil used?*

For reducing the voltage and current in a circuit. The self-induction of the choke coil acts as a C.E.M.F. or "back voltage" opposing the impressed or line voltage, and thus reducing the current. For example, a choke coil may be connected in series with a group of incandescent lamps in order to dim them. Choke coils are being used to a considerable extent for maintaining constant current in a series of arc lamps operated from a constant-potential alternator, the inductance of the coil being adjusted to compensate any changes of resistance due to the feeding of the arc-lamp carbons.

1475. *What advantage has a choke coil over a resistance coil?*

The resistance coil reduces the current on a line by increasing the resistance, but at the same time absorbing a considerable part of the energy. For example, suppose a group of lamps on a 110-volt circuit takes 10 amps., or 1100 watts. The resistance of the lamps is

$$R = E/I = 110/10 = 11 \text{ ohms.}$$

Now, suppose a resistance of 11 ohms is inserted in series with the lamps, and assume for simplicity that the considerable change in the resistance of the lamps (see Nos. 345 and 814) is negligible.

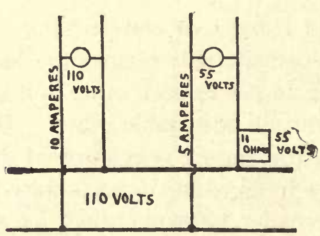


FIG. 1475.—EFFECT OF RESISTANCE.

The total resistance is $R = 11 + 11 = 22$ ohms. The current is $I = E/R = 110/22 = 5$ amperes. The total energy is the sum of

that in lamps and in resistance, or, energy is $I^2R = 5 \times 5 \times 22 = 550$ watts. The energy used in the lamps is $W = I\,R = 5 \times 5 \times 11 = 275$ watts, or only half the total energy, while the balance of 275 watts is absorbed by the resistance. By inserting an equal resistance, the energy used in the lamps is reduced to one-fourth while the total energy taken by the circuit is reduced to one-half. In other words, while the added resistance reduces the total energy taken by the circuit, it also wastes a large part of what is taken. On the other hand, the choke coil also reduces the total energy taken by the circuit, but does not waste much of it.

1476. *Is a choke coil suitable for direct currents?*

No. It is used only with alternating currents. With direct current it would act only as a very low resistance and would not materially reduce the voltage or the current.

1477. *How can a choke coil reduce the current without wasting energy?*

The choke coil sets up a C.E.M.F. which not only reduces the current, but also causes the current waves to lag behind the E.M.F. waves. The energy actually used is the product of the current by the component of the E.M.F., which is in the same phase. This may be illustrated by an enclosed alternating current arc lamp taking 5 amperes from a 112-volt circuit. The arc itself takes about 80 volts, acting partly as a C.E.M.F. in phase with the current and partly as an ohmic resistance. The coils in series, including the choke coil and the magnet coils which control the feeding of the arc electrodes, take about 52 volts nearly in quadrature with the current and with the voltage at the arc. The apparent energy taken is $80 \times 5 = 400$ volt-amperes by the arc, $52 \times 5 = 260$ volt-amperes by the coils and $112 \times 5 = 560$ watts by the whole lamp. The actual energy is about 395 watts by the arc and about 434 watts by the whole lamp, the difference being 39 watts absorbed by the coils. If the difference of 32 volts between the 80 at the arc and the 112 at the terminals had been absorbed by resistance, the energy loss would have been $32 \times 5 = 160$ watts instead of the 39 watts actually absorbed.

1478. *Is not the energy of an alternating current equal to the product of amperes by volts?*

Sometimes it is, but usually is not. When there is no lag between the current and voltage, that is, when the waves of current and pressure reach corresponding values simultaneously, both being at zero

at the same time and both being at positive maximum or other corresponding values at the same time, the simple product of amperes by volts gives watts. This is illustrated in the figure, which represents a circuit without induction, such as a group of incandescent

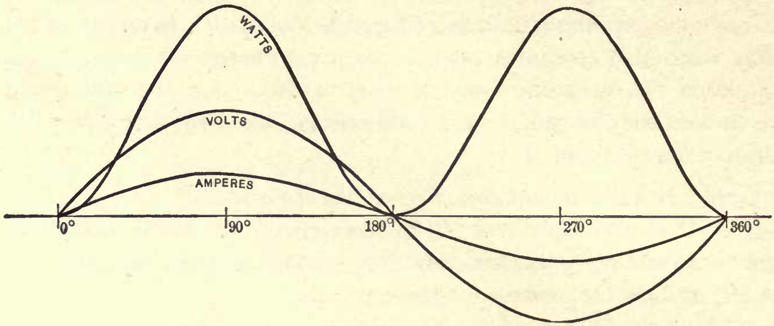


FIG. 1478.—ENERGY IN NON-INDUCTIVE CIRCUIT.

lamps, in which the current is in phase with the voltage. The energy at any instant is the product of current by voltage at that instant. The upper curve is plotted from the products of corresponding values

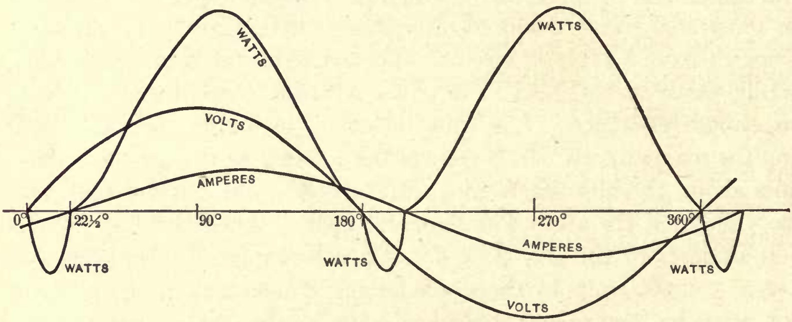


FIG. 1479.—POSITIVE AND NEGATIVE ENERGY IN INDUCTIVE CIRCUIT.

of current and voltage. The area enclosed between the watt curve and the base line represents the energy in the circuit. In the second part of the cycle, the current and voltage are both negative, but the energy is positive, since the product of two negatives is always positive. Distortion of either wave acts somewhat like phase difference.

1479. *How can the energy of an alternating current be different from the simple product of amperes by volts?*

If the circuit has self-induction or capacity, as is generally the case, the current waves are behind or ahead of the voltage waves, and

the true energy is less than the simple product of volts by amperes. This is illustrated in Figs. 1479 and 1481, which have current and voltage curves equal to those of Fig. 1478, but which have different watt curves. If the curves of current and voltage are not in the same phase, one will sometimes have a positive value when the other is negative, the result being that their product is negative for part of each cycle, as shown in Figs. 1479 and 1481. The area of the loop on the lower side between the base line and the watt curve represents negative energy; that is, energy that is returned to the line or source of supply.

1480. *How can a line deliver current or energy back to a generator?*

During parts of the cycle, the pressure on the line may be higher than that from the generator, and so send current back. A somewhat similar case is that of a steam engine; during part of the stroke, the piston drives the flywheel; then the wheel carries the system over the dead center.

1481. *How can an alternating current be wattless or without energy?*

This would occur in the extreme case when the current and E.M.F. curves are 90 degrees apart, one being at zero when the other is at a maximum, as indicated in the figure. The negative loop in the watt

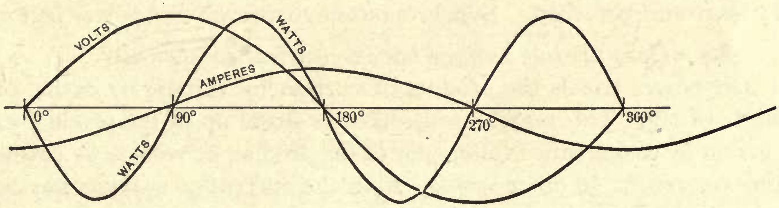


FIG. 1481.—WATTLESS CURRENT.

curve exactly equals the positive loop, and the line returns as much energy as it receives. This extreme condition never happens, but is closely approximated when a circuit has great self-induction and small resistance, as in the case of the primary coil of a transformer when the secondary circuit is open.

1482. *Is it correct to say that part of an alternating current is wattless and that the rest has energy or power?*

Yes. The whole current may be considered as being made up of two parts, one (called the "energy component," or "useful current") which is in phase with the impressed or line E.M.F., and one (called

the "wattless component," "idle current" or "wattless current") which is 90 degrees behind or ahead of it. (When the capacity in the circuit is more effective than the induction, the current leads the line pressure and the wattless component of the current is 90 degrees ahead of the active component. This condition is reversed when, as usual, the induction is stronger than the capacity). Although there is only one current in a series circuit, it may be thought of as being resolved into components, whose sum properly taken equals the whole. This is strictly analogous to the composition and resolution of forces. The ratio of the active component to the total current is called the "cosine of the angle of lag, or of lead."

1483. *What is meant by the "power factor"?*

The power factor is the ratio of the true watts to the apparent watts or volt-amperes. It may be considered as the ratio of the "useful" to the total current in the circuit. As explained in No 1482, the current in a circuit may be considered as made up of two components, of which only one is useful. The true energy in the circuit is the product of the line pressure by the active component of the current, which equals the product of volts by amperes by the cosine of the angle of lag. The power factor is never greater than unity and is generally less. With old style open arc lamps the power factor was sometimes as low as 0.30. With the modern enclosed arc lamps, the power factor varies from 0.45 to 0.85. With induction motors, it varies from 0.30 to 0.95. Synchronous motors reach 1.00 power factor.

1484. *Does the line voltage have a wattless component?*

The power equals the product of current by voltage by cosine of angle of lag. This may be considered as made up of the product of current by cosine times voltage, or of the product of voltage by cosine times current. In other words, either the current or voltage may be considered as resolved into components.

1485. *Why do writers on alternating currents use so many diagrams with circles or triangles?*

These are generally used to explain or to determine the relation between the various currents and E.M.F's that must be considered in discussing A. C. problems. With continuous currents the relations between current and E.M.F. are very simple, but in dealing with alternating currents and E.M.F's, one may be at its greatest value at a time when another is at its zero or any intermediate value. When, for example, the current and E.M.F. do not reach their highest values at the same time, as in Fig. 1499 or 1502B (which represent cases where self-induction causes the current to lag behind the

pressure), the watts can not be determined by simply multiplying current by volts, since that would give too large a result. By the use of geometry, we can easily determine the part of the E.M.F. which is in phase with the current, and can then get the watts by multiplying the current by that part of the E.M.F. To do this, we must know how to resolve the whole E. M.F. into its elements. By a simple geometric method, we can find what will be the result of adding two or more E.M.F's or currents that have any difference of phase. By reversing the same process, we can take any E.M.F. or current and find what two or more elements might have been combined to make it, or if we know one of the elements, we can easily find the other. This process is an application of what is generally called "the resolution of forces."

1486. *How can the resultant of two or more forces be determined graphically?*

The forces may be represented in direction and amount by straight lines drawn in suitable directions and of such length as to represent to any convenient scale the amount. For example, let *A* and *B* in the figures represent two horses pulling in the directions shown, the length of the lines representing the strength with which each horse pulls. Then their combined pull equals that which might be given

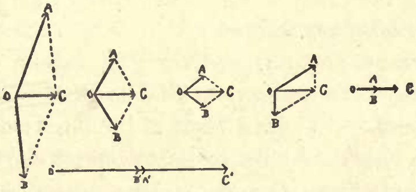


FIG. 1486.—COMPOSITION OF FORCES.

by a third horse pulling in the direction, *C*, and to the amount indicated by length of line, *C*. The direction, *C*, is found by drawing lines through *A* parallel to *B* and through *B* parallel to *A*. The line drawn from the intersection of *A* and *B* to the intersection of the lines parallel to them represents in direction and in amount the resultant. When there are more than two component forces, these may be combined in pairs and the resultant of the pairs may then be treated as components. It is clear from the last figure at the right that if the two component forces are in exactly the same direction, their resultant is in the same direction and equals their arithmetical or algebraic sum. But if the component forces are not in the same direction, their geometrical or trigonometrical sum must be taken. For example, in the figure at the left, if *A* and *B* were in the same

direction, their sum would be *o c'*, as shown in the lower part of the figure, instead of the smaller resultant, *o c*.

1487. *How can a force be resolved into its components?*

The simplest way is by geometry or trigonometry. Any force or resultant may be resolved into any desired number of components, and any, or all, of the components may be equal to, or greater or smaller than the resultant, as seen in Fig. 1486. There may be any number of pairs of components derived from any one resultant, and it is necessary to fix certain conditions if one is to obtain a definite desired pair. Since each resultant is determined by its length and direction, each solution involves two directions and two lengths. If both lengths are given, or both directions, or one direction and one length, the solution is easy.

1488. *How can the components be determined when their directions are known?*

Draw the resultant first, as *O C*, of Fig. 1486. Then from *O* draw lines in the proper directions, but of indefinite length. Then from *C* draw lines parallel to *O A* and to *O B*. The points where these cross determine the lengths of *O A* and *O B*. This problem has only the one solution.

1489. *How can the components be determined when their lengths, but not their directions, are known?*

Draw the resultant, *O C*, first, as in Fig. 1489. From each end as a center draw two circles, each with a radius equal to one of the two forces. From *O* and *C* draw lines to the points where the larger circle drawn from *O* is cut by the smaller circle drawn from *C*. Draw lines parallel to these from *O* and *C* to the point where the smaller circle drawn from *O* is cut by the larger circle drawn from *C*. Then

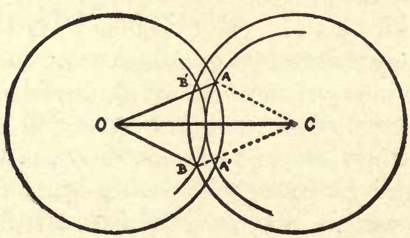


FIG. 1489.—DETERMINATION OF COMPONENTS.

O A and *O B* are the components sought. It is seen also that another solution may be had by drawing a parallelogram on *O B' C A'*, so that this problem has two solutions, unless the two components are equal.

1490. *How can the components be determined when the direction of one and the length of the other are known?*

Draw the resultant, $O\ C$, as in Fig. 1490. From O draw a line of indefinite length in the known direction of one force. From C draw a circle with a radius representing on the proper scale the known force. Draw a radius from C to the point where the circle crosses

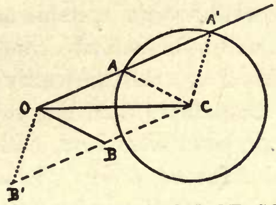


FIG. 1490.—DETERMINATION OF COMPONENTS.

the line. From C also draw a line parallel to $O\ A$, and from O draw a line parallel to $C\ A$. Then $O\ A$ and $O\ B$ are the two components desired. It is seen that the line may cut the circle in two places, giving the second parallelogram, $O\ A'\ C\ B'$, and the two components, $O\ A'$ and $O\ B'$. If the line does not cut or touch the circle at all, there is no solution.

1491. *Of what value is this geometry for studying alternating currents?*

It enables one to solve many problems that otherwise would be very difficult. For example, if one knows the amperes, volts and angle of lag, it is easy to determine the watts graphically or by a geometric method similar to the above. Or, knowing the amperes and angle of lag between the voltage and current, it is easy to determine the amount of the wattless component of the current.

1492. *How can one determine the wattless component of the current when the angle of lag is known?*

This may be determined by the method given in No. 1487. The

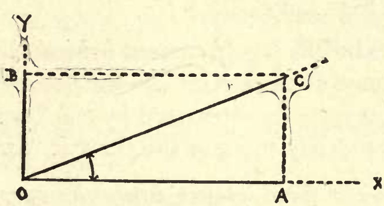


FIG. 1492.—DETERMINATION OF WATTLESS COMPONENT.

current is to be resolved into two components, one representing the active current in phase with the E.M.F., and the other representing

the wattless current at right angles, or 90 degrees behind it. From any point, *O*, taken as the origin, draw (as in Fig. 1492) an indefinite horizontal line, *O X*, representing the E.M.F., and the direction of the active component of the current. From *O* draw another line, making an angle, *C O X*, equal to the angle by which the current lags behind the E.M.F. Lay off a distance, *O C*, on this second line which shall represent on a suitable scale the total current. Now it is desired to resolve *O C* into two components, one of which shall be in the direction, *O X*, and the other at right angles to it. From *C* draw a line, *C B*, parallel to *O X*, and another line perpendicular to it. Draw a perpendicular line, *O Y*, from *O*. Then we have the parallelogram of forces, *O A C B*, and the components of *O C* are *O A* and *O B*. In other words, *O C* represents the actual current flowing, *O A* is the component of it which is active or in phase with the E.M.F., and *O B* is the wattless component.

1493. *What is meant by the "angle of lag?"*

This is a convenient method of indicating the "difference of phase" between the current and E.M.F. An alternating current is usually more or less out of phase with the E.M.F. causing it; that is, the current reaches its greatest or maximum value after the E.M.F. has reached its maximum. Current and E.M.F. each take the same amount of time to complete a cycle or complete alternation, but the current is usually a little later than corresponding values of the E.M.F. causing it. In order to measure the amount of this dragging behind, the time of a complete cycle is considered as being divided into 360 equal parts or degrees, the most convenient place to begin numbering being the point where the E.M.F. or current passes through zero. The angle of lag between current and E.M.F. is shown by the distance (measured in degrees) between corresponding values; for instance, the distance between the points where the two curves cross the base line in the same direction, as at *A* and *B*, in the upper diagram of Fig. 1499.

1494. *What causes the lag of current behind the E.M.F.?*

The self-inductance of the circuit causes the current to lag behind the E.M.F. This may be counteracted by the "capacity" of the circuit, which has a tendency to make the current "lead" the current.

1495. *How does self-inductance cause the current to lag behind the E.M.F.?*

In any circuit having self-inductance there is a tendency to prevent changes in the strength of the current. Every current is surrounded by a magnetic field which is caused by, and is proportional to, the

strength of the current. When two parts of the circuit are near together, so that one is in the magnetic field of the other, any change in the strength of the current causes a corresponding change in the magnetic field and so sets up an E.M.F. in the other wire. Each part reacts on the other, and in a coil the induced E.M.F. is proportional to the square of the number of turns of wire. This induced E.M.F. is in a direction to oppose the change in the current and is therefore called a "counter E.M.F." In the case of an alternating current, this therefore causes the current to reach its maximum value a little later than the line or impressed E.M.F.; the same tendency also causes the current to hold up after the E.M.F. has diminished. Thus the result of the E.M.F. of self-inductance is to make the current lag behind the principal or impressed E.M.F.

1496. *Is the E.M.F. of self-inductance directly opposed to the impressed E.M.F.?*

No. It is about 90 degrees behind the current, and therefore is nearly opposite the impressed or line E.M.F. The E.M.F. of self-inductance is at every instant proportional to the rate of change of the current. When the current is at its maximum value, it is chang-

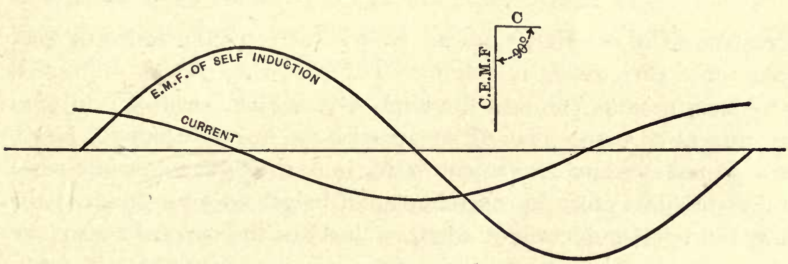


FIG. 1496.—RELATION OF CURRENT AND C.E.M.F.

ing least rapidly—in fact, has a constant value for an instant—and therefore the induced E.M.F. at that instant is zero; when the current is zero it is changing most rapidly, and therefore the induced E.M.F. is at its maximum value. The E.M.F. of self-inductance is therefore 90 degrees behind the current, as is indicated in the figure.

1497. *What governs the angle of lag between the impressed or line E.M.F. and the current?*

The lag is governed by the relative values of the various E.M.F's in the circuit. In a circuit having resistance and self-inductance, but no capacity worthy of notice, three E.M.F's must be considered: that on the line, or the impressed; that due to self-inductance; that due to the "ohmic drop," which equals current times effective re-

sistance, as with continuous currents. The ohmic drop, sometimes called the "effective" or "active" E.M.F., is at all times proportional to the current and is therefore in phase with it. As shown in No. 1494, the E.M.F. of self-inductance is 90 degrees behind the current. These are the two components into which the impressed E.M.F. may be resolved, and from which the angle between the current and impressed E.M.F. may be determined. For example, suppose a coil has

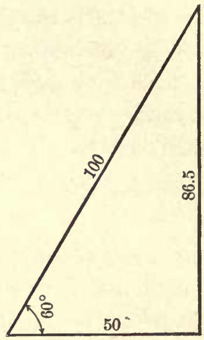


FIG. 1497.—E.M.F.—DIAGRAM.

a resistance of 10 ohms and an E.M.F. of self-inductance of 86.5 volts when the current is 5 amps. The ohmic drop is 10 multiplied by 5, or 50 volts. To find the impressed E.M.F. necessary to send the current of 5 amps., lay off on a horizontal line a distance to represent 50 volts to any convenient scale, as in the figure. At the right end of this line erect a perpendicular of length 86.5 to represent the E.M.F. of self-induction 90 degrees ahead of the current and ohmic drop. The line joining the ends of the two lines represents in direction and amount the impressed E.M.F. necessary to send the current through the circuit. From the figure, this is seen to be 100 volts. The angle between the impressed E.M.F. and the ohmic drop, and therefore the current, is seen to be 60 degrees. Knowing the angles between the various E.M.F's and the current, it would be easy to plot curves similar to Figs. 1496 and 1499 for this case.

1498. *How is a sine curve constructed?*

At one end of a straight line, *X X,* draw a circle with a radius equal to the highest ordinate of the proposed curve; divide the circle into quadrants (quarters) by drawing the vertical line, 90-270; by striking short arcs, *a* and *b,* from 90 to 180, and drawing a line from their intersection through the center, *c,* the circle is divided into two further parts at 135 and 315 degrees; by striking other arcs from

135, cutting the arcs from 180 and 90, and drawing lines from these intersections, the circle is divided into smaller parts; this process may be continued as far as desired. On the line. *X X*, lay off as many points an equal distance apart as there are divisions in the circle, making the distance between the points such that the total distance,

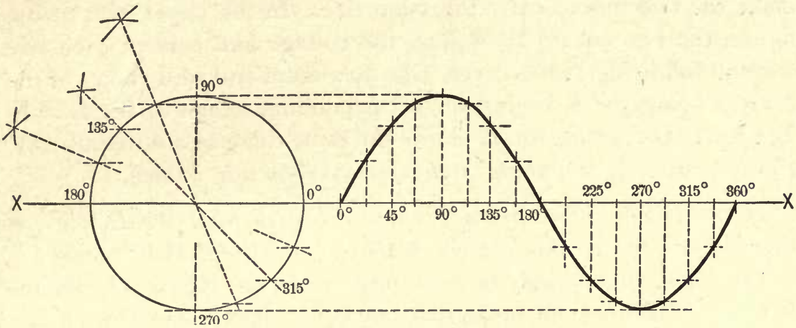


FIG. 1498.—CONSTRUCTION OF SINE CURVE.

0 to 360, will be the desired length of the curve; number these points to correspond with the divisions of the circle, and draw vertical lines at each division. Draw lines across from the intersection points on the circle until they cross the corresponding vertical lines and draw the curve through the points thus found.

1499. *How can the angle of lag be determined experimentally?*

The angle of lag can be calculated if the amperes, volts and watts are known; for the watts equal the product of amperes by volts by cosine of the angle of lag. (The mathematical proof of this is somewhat complicated and will not be given here). Dividing the watts

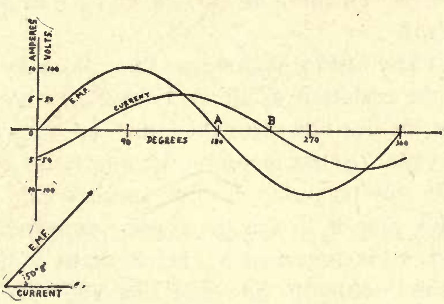


FIG. 1499.—CURRENT LAGGING BEHIND E.M.F.

by the product of amperes by volts gives the cosine of the angle of lag, from which the angle itself can be found by referring to a table of sines and cosines. For example, a small induction motor is found

to take 400 watts at 104 volts and 6 amps. Dividing 400 by the product of 104 by 6, or by 624, gives 0.641 as the cosine of the angle of lag. Referring to a table, we find that 0.641 is the cosine of 50° 8′. Fig. 1499 shows the relation of current and voltage for this case, the current being plotted to a larger scale than the voltage in order to make the two more nearly the same size. In the upper part of the figure, the two curves show how the voltage and current each rise and fall following "sine curves," the maximum and zero values of the current being 50° 8′ behind the corresponding values of the E.M.F. The lower part of the figure shows the same thing in a different way, showing directly the angle between corresponding values.

1500. *When an alternating current lags behind the E.M.F., is there not a considerable current at times when the E.M.F. is zero?*

Yes. The current may be quite large when the E.M.F. on the line is zero. This does not mean that one could get current from a line that showed no E.M.F. when tested with a suitable voltmeter, for no current would flow under such conditions. It is true, however, when an alternating E.M.F. causes current to flow, that the E.M.F. varies from zero to maximum values many times each second, and that the current may be quite large at an instant when the E.M.F. is zero.

1501. *Does not Ohm's law hold true for alternating currents?*

Yes, it does when properly interpreted and applied. It holds true for instantaneous values, the current at any instant equaling the pressure at that instant divided by the equivalent resistance. Taking mean values, impedance is to be substituted for resistance.

1502. *Then how can there be current flowing at an instant when the E.M.F. is zero?*

The current at any instant is governed not alone by the E.M.F. on the line, but by the resultant of all the E.M.F's acting. A voltmeter connected across the line measures the "line" or "impressed" E.M.F., which is nearly equal to that given by the alternator or transformer; there is generally in alternating circuits another E.M.F. due to self-inductance on the line or in the apparatus connected with it. The current in the circuit is governed by the resultant of the two or more E.M.F's acting, and not by the line E.M.F. alone. The other E.M.F's are practically never in exact step (that is, in the same phase) with the line E.M.F., and therefore the resultant E.M.F. may have a considerable value at an instant when the line E.M.F. is zero. For example, suppose that the lines in Fig. 1502A marked "Line E.M.F." and "C.E.M.F." represent to any convenient scale the mean values

of the E.M.F. on the line, and the E.M.F. due to self-inductance (sometimes called the counter-electromotive force, or C.E.M.F.), and let the angle between them represent the angle between corresponding maximum values of these quantities. These two E.M.F's

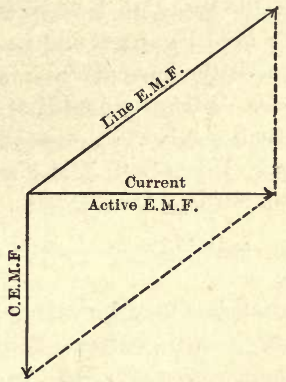


FIG. 1502A.—COMPOSITION OF E.M.F.'S.

may be combined and their resultant found by the method explained in No. 1486. The resultant of the two E.M.F's gives what is sometimes called the "active" E.M.F. which is effective in causing the current. The relations between the instantaneous values of the two E.M.F's and the resulting current are shown in Fig. 1502B, the cur-

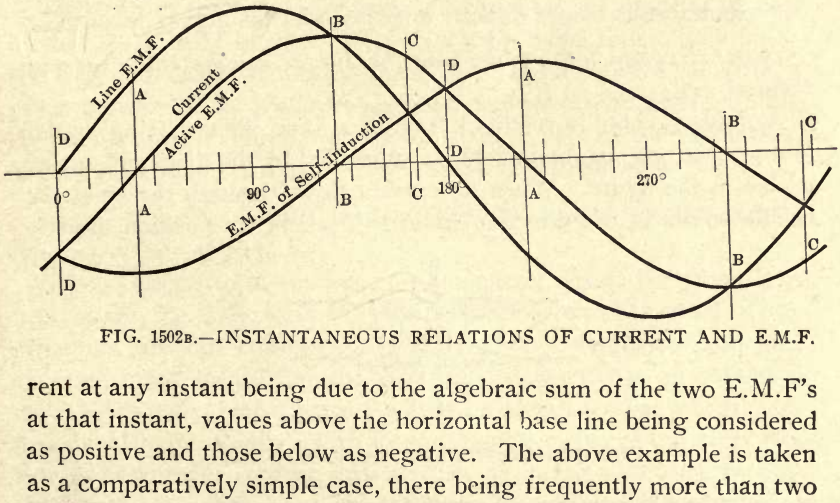


FIG. 1502B.—INSTANTANEOUS RELATIONS OF CURRENT AND E.M.F.

rent at any instant being due to the algebraic sum of the two E.M.F's at that instant, values above the horizontal base line being considered as positive and those below as negative. The above example is taken as a comparatively simple case, there being frequently more than two E.M.F's in practice. This example shows in an elementary way how the current may have a considerable value at an instant when the

E.M.F. on the line is zero. Fig. 1502B is drawn to represent a case in which the line E.M.F. is 100, E.M.F. of self-induction is 60 and current (or active E.M.F. causing current) is 80. The current lags behind the E.M.F. by about 34 degrees and the E.M.F. of self-induction is 90 degrees further behind. When the two E.M.F's are equal as at *A A* in the figure, the resultant E.M.F. is zero and the current is also zero. When the E.M.F. of self-induction is zero, as at *B B,* the resultant E.M.F. equals the line current and the current is caused by the line E.M.F. alone. When the line E.M.F. is zero, as at *D D,* the resultant E.M.F. equals the E.M.F. of self-induction and the current is caused by it alone. When both E.M.F's are in the same direction, as at *C C,* the resultant equals their sum.

1503. *How can the C.E.M.F. or E.M.F. of self-induction be measured?*

It can not be measured, but may be calculated from the triangle of E.M.F's when the line E.M.F., current, resistance, frequency, lag and coefficient of self-induction are known. In simple cases, only the line E.M.F., current and angle of lag need be known.

1504. *How can the shape of the curves of current and of E.M.F. be measured when the whole cycle is completed in a very small part of a second?*

The curves may be printed automatically by means of photography with the use of galvanometers having very light sensitive and rapidly moving parts. The more tedious method is to measure the instantaneous values directly and then plot the curves from these.

1505. *Explain more fully how the curves can be made to print themselves?*

A galvanometer is required, having a very light moving system in a very strong magnetic field, as suggested by the diamond-shaped needle in the figure. When no current flows through the coils, the needle points in the direction indicated, taking its position directly

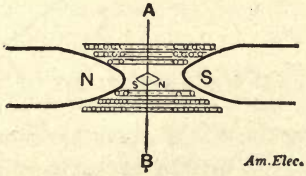


FIG. 1505.—SECTION OF GALVANOMETER.

in the path of the magnetic lines of force between the poles, *N* and *S*. Current through the coils tends to place the needle in the direction of the line, *A B,* at right angles to its other position. When the

needle is under the influence of both forces at the same time, it will take an intermediate position. Now if the current varies in amount or direction or both, the needle will respond and take a position at every instant corresponding to the relative strength of the current. A beam of light reflected from the needle or from a small mirror attached to it, will take a record upon a photographic plate which is moved at a regular speed in a direction perpendicular to the motion of the light. For this purpose a very sensitive instrument is required, and the amateur had better not waste time in trying the experiment. This is outlined simply to give a general idea of how it is done. The step-by-step method is tedious, but is delicate to handle. The automatic device is called an oscillograph.

1506. *What is the step-by-step method of determining the instantaneous values of an alternating E.M.F. or current?*

There are a number of methods, all being dependent upon the fact that no matter how rapidly the current or E.M.F. passes through a cycle, each cycle is exactly like those preceding and those following. For example, if in the curve in Fig. 1498, the distances above and below the center line represent the variation of an alternating current through a single cycle, the current will pass through exactly the same set of values many times each second. In the armature of an alternator there are usually as many coils as there are poles in the field. These are connected in series and are placed symmetrically with reference to the magnet poles, so that the E.M.F's in the various coils are all in the same direction and equal at any instant; that is, so that the E.M.F. in each coil is zero at the same time. So long as the load and speed are steady, the E.M.F. has a definite value for a given position of the armature; hence if contact can be made with the circuit for a very short time at some definite part of the revolution, the pressure may be measured by a suitable instrument.

1507. *What apparatus is necessary for measuring the instantaneous values of E.M.F.?*

It is necessary to have some sort of contact device by which connection may be made with the circuit at any desired position of the armature, also an electrostatic voltmeter or a condenser and galvanometer for measuring the E.M.F. Suppose that an insulated metallic disc is mounted upon the armature shaft so that a brush can make continuous contact with it, and having a projection from one side so as to make contact with a wiper or spring once each revolution. It is plain that the wiper will make contact with the projection from the disc at the same point in the revolution of the armature, no matter how rapidly the armature may be rotating. Now suppose

that a sensitive voltmeter is connected on one side to one of the mains carrying current from the machine, and on the other side to the brush making continuous contact with the insulated disc, and that the wiper brush is connected to the other main, as suggested in Fig. 1507a. The wiping brush completes the circuit through the voltmeter once every revolution of the armature and at identically the same point in the revolution. The voltmeter will therefore receive

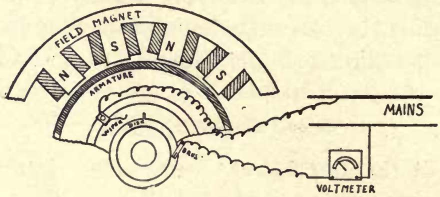


FIG. 1507A.—INSTANTANEOUS CONTACT DEVICE.

current from the mains for an instant, and the needle or pointer will be deflected, a certain amount depending upon the voltage between the mains at the instant the contact is made. By moving the wiper to other positions, the corresponding voltages may be determined

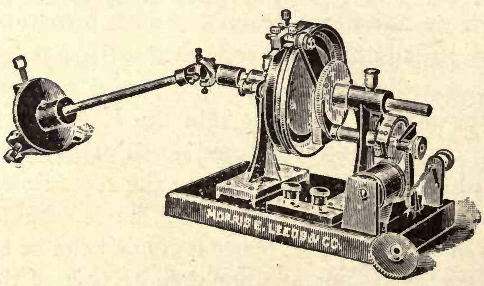


FIG. 1507B.—PORTABLE CONTACT MAKER.

for various positions. By properly calibrating the voltmeter, the actual voltage between the two mains at the instant of contact may be determined for each position, and a curve may be plotted, using the successive positions of the wiper as horizontal distances, and the corresponding voltages as the vertical distances. There are many details to be looked after for accurate results and many different arrangements of the apparatus have been used, such as illustrated in Fig. 1507b, but they are all essentially the same as outlined above.

1508. *How can the curve for the alternating current be obtained by such a device?*

A small non-inductive resistance may be placed in series with one of the mains so as to carry the current to be measured. By Ohm's

law, the fall of potential through the resistance is directly proportional to the current. Pressure wires from the ends of the resistance to the contact device and voltmeter as before, enable us to measure the drop through the resistance at different points, and so to calculate the current and to plot a curve for the current in the same way as was done for the voltage between the mains. For measuring the current by this method, it is necessary to have the voltmeter sensitive, since the drop in voltage through the resistance will not be large.

1509. *How can the relative positions or the difference of phase between the current and voltage be determined?*

By having suitable switches, the wires to the contact device may be connected first to one circuit and then to the other, so as to determine the current and then the voltage corresponding to each position before the wiper is moved to a new position. In this way corresponding values for primary current, primary voltage, secondary current and secondary voltage may be determined.

1510. *What is a rotary converter?*

A rotary converter is a machine for changing an alternating current into a continuous current, or *vice versa*. It is practically a

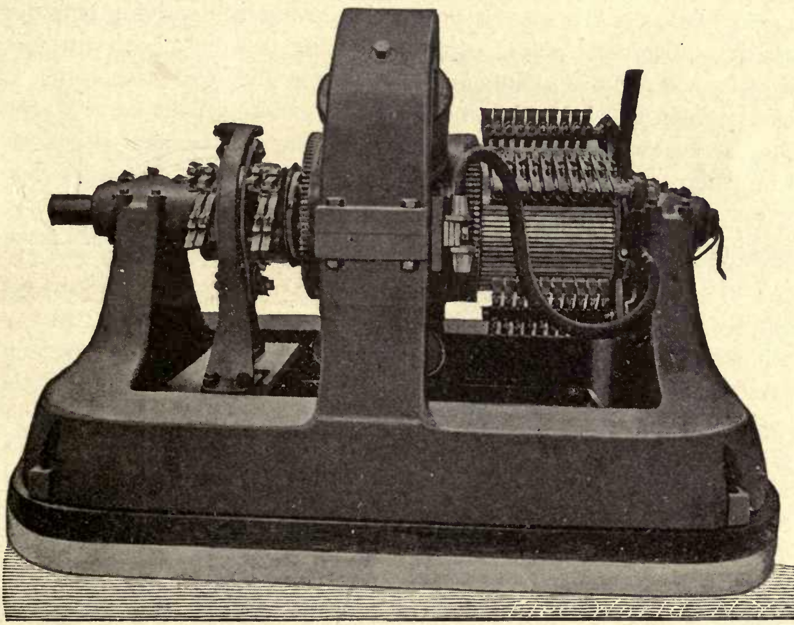


FIG. 1510.—A ROTARY CONVERTER.

continuous-current motor with a set of collecting rings at one end like the rings of an alternator. If continuous current is supplied at

the commutator, alternating current may be taken from the collecting rings. On the other hand, if the machine is supplied with alternating current at the rings, continuous current may be taken from the commutator. The machine is often supplied with a pulley so that it can be used as a motor to furnish power, or may be driven as a dynamo to generate either continuous or alternating current. Such a machine is illustrated in Fig. 1510, in which the commutator for continuous current is seen between the field magnet and the bearing at the right, while the three collecting rings for three-phase alternating current are seen at the left between the bearings and the field magnet.

1511. *What is the difference between a rotary transformer and a rotary converter?*

These are simply two names for the same thing. They are often called simply "rotaries." The better term "converter" or "synchronous converter" is recommended by the American Institute of Electrical Engineers.

1512. *Explain how a synchronous converter changes current from alternating to continuous.*

Let Fig. 1512 represent a simple ring armature revolving between a pair of magnetic poles; suppose the ring is wound with wire, as shown, two opposite points being connected with collecting rings, *C* and *C*, upon which brushes make contact to take off the current; for the present neglect the commutator and the two brushes shown in heavy lines. When the armature is in the position shown, all the wires on each half are sending current in the same direction, say, up, making the outer ring positive and the inner ring negative. Now

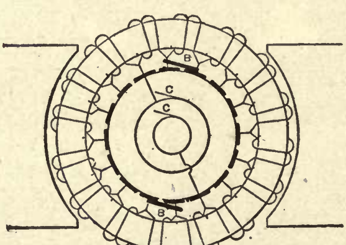


FIG. 1512.—DIAGRAM OF ROTARY TRANSFORMER.

suppose the armature has revolved a quarter turn so that the connecting wires are horizontal instead of vertical, as in the figure; then, as before, all the wires on each side are trying to send current up toward the top, but there is no connection at the top to take it off; the

E.M.F's on the two sides of each half are opposed and exactly equal, so that there is no net E.M.F. between the collecting rings, and there is no current at that instant. Between these two positions, the current and E.M.F. vary more or less uniformly, each following closely the sine curve described in No. 1498. Next suppose that the armature is provided with a commutator, each section of the winding being connected with a commutator bar, as suggested by the circle of heavy lines; the brushes, *B* and *B*, will make contact with different bars and therefore with different sections of the armature winding, unlike *C* and *C*, which always connect with the same armature section. It is seen that the armature wires between *B* and *B* all tend to send current in the same direction at all positions of the armature, so that a continuous current may be taken from *B* and *B*, while at the same time an alternating current may be taken from the same armature by *C* and *C*. Since either a continuous or an alternating current may be obtained from the same armature, it makes no difference what causes the armature to rotate, whether mechanical power applied at the pulley or electrical power applied at either pair of brushes. As was explained in Nos. 1336 and 1346, under Direct-Current Motors, the same armature is equally adapted for use as a dynamo or as a motor. Therefore, if continuous current be applied to the brushes, *B* and *B*, alternating current may be taken from the brushes, *C* and *C*. Similarly, if alternating current be supplied through the brushes *C C*, the machine will run as an alternating-current motor, and direct current may be taken from the brushes *BB;* when driven by direct current, it is called an "inverted rotary."

1513. *In a synchronous converter, is the voltage between the alternating-current brushes the same as between the continuous-current brushes?*

No. The alternating voltage is only about seven-tenths of the continuous voltage. By reference to Fig. 1512 it is seen that the alternating voltage is at a maximum when the armature coils connected with the collecting rings are also connected with the continuous-current brushes. The maximum value of the alternating voltage is therefore equal to the steady value of the continuous voltage. But the effective or mean value of the alternating voltage, supposing it to follow the sine curve, is only 71 per cent of the maximum. For example, if the continuous voltage is 500, the alternating voltage is $500 \times 0.71 = 355$. In practice the alternating voltage is somewhat less than the simple theory calls for, being influenced by the setting of the brushes, the distribution of the magnetic field and some complex elements. (See also No. 1517.)

1514. *What kind of alternating current is given by a synchronous converter, such as described in 1512?*

Such a rotary with only two collecting rings would give a single phase or monophase current.

1515. *How could a two-phase current be obtained?*

Two-phase currents could be obtained by having a second pair of collecting rings connected to the armature winding at points midway between the first ones. The E.M.F. between the second pair would be at a maximum when that between the first pair was at zero. The two currents would thus be at right angles, or in other words, in quadrature, or 90 degrees apart. The effective values of the two E.M.F's would be equal.

1516. *How can three-phase current be obtained from a converter?*

By connecting three collecting rings to three equidistant points, as suggested in Fig. 1516.

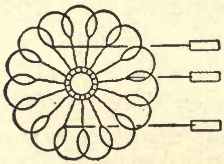


FIG. 1516.—DIAGRAM OF THREE-PHASE ROTARY CONVERTER.

1517. *What is the relation between continuous and alternating voltages in a three-phase rotary converter?*

According to the elementary theory, the effective voltage between any two of the three lines is 62 per cent of the continuous voltage. Actually it is somewhat less, for reasons similar to those mentioned in No. 1513.

1518. *Will a rotary converter also obtain a continuous current from an alternating current?*

Yes. If the motor is arranged so as to be driven by alternating current supplied through the collecting rings, then a continuous current can be taken from the brushes, *A B,* bearing on the commutator.

1519. *Are rotary converters used much?*

They are largely used in railway and other sub-stations for obtaining continuous current from an alternating plant.

1520. *What is a static transformer?*

Static transformer is a trade or shop name used for the ordinary transformer for stepping voltages up or down, to distinguish it from the rotary transformer, which is used to convert alternating into continuous currents, or *vice versa.*

APPENDIX I.

OUTLINE OF ELECTRICAL CHRONOLOGY.

Condensed principally from Benjamin, "The Intellectual Rise in Electricity," Appleton, 1895; Mottelay, "Chronological History of Electricity and Magnetism," *Electrical World,* 1892-3; Fahie, "History of Electric Telegraph," Spon, 1884; Fahie, "History of Wireless Telegraphy," Blackwood, 1900; Cajori, "History of Physics," S. P. Thompson, "Dynamo Electric Machinery," and "Elementary Lessons"; which writers give detailed references to original sources.

B.C.

2637 Hoang Ti uses compass in China (?).
2000 Copper plated (?) clay cylinders in Egypt.
1000 Lightning protection on Solomon's temple.
600 Thales notes electrostatic attraction to amber (electron).
600 Etruscans draw lightning from clouds by metal arrows (?).
425 Euripides writes of attraction of iron to lodestone.
341 Aristotle writes of the electric fish (torpedo).

A.D.

77 Pliny writes of thermoelectric crystals and of St. Elmo's fire.
425 Zosimus notes coating of iron with copper by immersion.
426 St. Augustine distinguishes between magnetic and electric attraction.
1000 Marine compass used by Finns.
1269 Petrus Peregrinus describes magnetic laws and a magnetic motor.
1544 Hartmann notes dip of compass.
1600 Gilbert writes "De Magnete"; makes electroscope and magnetometer.
1620 Bacon writes "Novum Organum," the first "Natural Philosophy."
1650 Von Guericke makes electric machine; discovers conduction and electric polarity.
1655 Digges (first American electrician) notes static sparks from clothes; also American fireflies.

1675 Isaac Newton discovers electrostatic induction.
1678 Swammerdam notes frog leg contraction by contact with silver and copper.
1729 Gray distinguishes between conductors and insulators.
1733 Dufay distinguishes between vitreous and resinous electricity.
1745 Winckler, Von Kleist and Musschenbroeck independently make condensers.
1746 Gralath makes electrometer, first electrical measuring instrument.
1746 Maimbray and Nollet note effects of electrification on weight of animals and plants.
1747 Watson uses earth return circuit; notes relative conductivities of branched circuits.
1752 Sulzer notes taste when lead and silver touch tongue.
1752 Franklin shows identity of lightning and electricity; effect of points; lightning rod; positive and negative electricity.
1786 Galvani notes contraction of frog leg by touching unlike metals.
1790 Paetz and Van Troostik decompose water by sparks.
1792 Volta proposes contact theory of electrification.
1799 Volta constructs " galvanic " pile.
1800 Nicholson and Carlisle decompose water by current.
1800 Wollaston plates copper on silver by electrolysis.
1800 Davy determines electromotive series of metals; makes arc light with carbon electrodes.
1801 Gautherot notes polarization and reverse current.
1801 Trommsdorff burns metal by current.
1803 Ritter notes polarization and makes secondary cell.
1806 Berzelius publishes his electrochemical theory.
1806 Grotthus publishes theory of electrochemical decomposition.
1807 Davy decomposes potash and soda electrolytically.
1809 Sommering operates electrochemical telegraph 1000 feet.
1812 Zamboni constructs his " dry pile."
1812 Schilling makes rubber-covered insulated wire.
1815 Dessaignes finds thermoelectric currents.
1815 Wollaston makes battery with large surface (low internal resistance).
1820 Sweigger constructs " multiplier," the first galvanometer.
1820 Oersted discovers electromagnetic action of current.
1820 Ampere discovers equivalence of electric current and magnetic shell; electrodynamic theory.
1820 Arago discovers electromagnetic rotation (eddy currents).

1821 Faraday obtains rotation of conductor about magnet pole.
1823 Barlow rotating disk motor.
1825 Sturgeon makes electromagnet.
1826 Poggendorff applies mirror to magnetometer.
1827 Ohm publishes law of electric circuit.
1829 Poisson proposes absolute values for magnetic field.
1829-30 Henry distinguishes between "quantity" and "intensity" winding of electromagnet; invents bobbin or spool winding.
1831 Faraday finds E.M.F. induced in coil by permanent or electromagnet; constructs disk dynamo (unipolar and homopolar).
1831 Henry constructs electric motor with commutator; sends signals electromagnetically.
1832 Henry discovers self-induction and mutual induction.
1832 Dal Negro makes an oscillating A.C. generator.
1832 Pixii makes rotating dynamos without and with commutators.
1833 Lenz announces law of direction of induced currents.
1833-8 Gauss and Weber telegraph with mirror galvanometer.
1834 Faraday discovers law of electrochemical equivalents.
1834 Gauss and Humboldt propose German magnetic units.
1835 Davenport operates miniature electric railway in New England.
1836 Daniell constructs constant-current battery.
1837 Steinheil uses earth return on telegraph system.
1837 Morse constructs electromagnetic dot-and-dash telegraph recorder.
1837 Sturgeon shuttle-coil armature and two-part commutator.
1839 Jacobi discovers electrotyping.
1840 Grove makes incandescent lamp with platinum filament.
1840 Pinkhus patents supplying moving car from stationary conductors.
1841 Wheatstone dynamo with multiple-coil armature giving continuous current.
1841 Deleuil and Archereau arc light with enclosed carbons.
1842 Grove makes gas battery.
1842 Henry discovers oscillatory character of Leyden jar discharge.
1842 Masson and Breguet make Ruhmkorff induction coil.
1845 Wheatstone and Cooke use electromagnets for dynamo fields.
1845 Faraday discovers electromagnetic property of light.
1846 Bain automatic telegraph with chemical receiver.
1846 Gauss and Weber propose absolute units of resistance.
1846 First paid use of electric light in "The Prophet," an opera.
1840 Mirand invents electric bell (vibrating or "trembling").

1850 Page operates 10 hp electric automobile in Washington.
1850 Jacobi finds dynamo and motor interchangeable.
1855 Bessolo patents use of third rail for electric supply (telegraph).
1857-8 Cyrus Field lays first transatlantic cables.
1859 Farmer lights house by platinum incandescent lamps.
1860 Plante makes storage battery.
1861 British Association adopts "B.A." unit of resistance.
1862 Arc light in Dungeness lighthouse, Holmes alternator.
1864 Maxwell shows mathematical equivalence of light and electricity.
1866 First successful transatlantic cable.
1867 Werner Siemens makes self-exciting dynamo.
1867 Pacinotti makes toothed armature (open coil winding).
1868 Stearns duplex telegraph.
1871 Gramme ring armature with continuous circuit.
1871 Hefner Alteneck drum-wound armature.
1873-4 Heaviside and Edison invent quadruplex telegraph.
1873 Rowland law of magnetic circuit analogous to Ohm's law.
1873 Fontaine and Gramme transmit power from generator to magnetic motor at Vienna Exposition.
1876 Bell exhibits telephone at Philadelphia Centennial Exposition.
1876 Brush operates arc lamps in series.
1877 Jablochkoff uses transformers in series on A.C. circuit.
1878 Hughes invents microphone.
1878 Avenue de l'Opéra in Paris lighted by arc lamps.
1879-81 Brush, Metzger and Faure make "pasted" storage batteries.
1879 Siemens & Halske third rail electric railway at Berlin Exposition.
1879 Edison makes incandescent lamps with high resistance carbon filament in vacuum.
1879 California Electric Light Co. incorporated for series arc lighting.
1881 Joubert founds modern theory of A.C. machines.
1881 International Congress adopts "C.G.S." units.
1881 First commercial electric railway in Berlin.
1882 Electric power transmitted 37 miles to Munich Exposition, 1 hp, 38 per cent efficiency.
1882 Edison station in New York for incandescent lighting at constant potential.
1883 Car operated in Paris by storage batteries.

1883 Gaulard and Gibbs use transformer for constant potential service.
1883 Hopkinson improves magnetic circuit of dynamo.
1884 Bentley-Knight conduit railway in Cleveland.
1885 Henry builds electric railway with overhead conductors in Kansas.
1885 Ferraris discovers rotary field.
1886 Cowles produces aluminum alloys in electric furnace.
1886 Stanley distributes alternating current with step-down transformers in multiple.
1888 Tesla constructs rotary field alternating current motor.
1888 Hertz demonstrates electric waves.
1888 Sprague constructs first modern electric railway at Richmond.
1889 Hall produces pure aluminum in electrolytic furnace.
1890 Branly discovers coherer.
1891 Borchers produces calcium carbide in electric furnace.
1891 Courts decide telephone interests do not own the earth as return circuit.
1891 Power transmitted 110 miles Lauffen to Frankfurt, three-phase, 16,000 volts, 200 hp.
1893 International units adopted, including watt, joule and henry.
1893 Howard and Marks introduce enclosed arc lamp.
1893 Gray invents autographic writing telegraph.
1894 Acheson produces carborundum in electric furnace.
1895 Electric power transmitted from Niagara Falls.
1895 Röntgen discovers X-rays.
1895 Electric locomotives supplant steam locomotives at Baltimore.
1895 Three-phase A.C. railway opened at Lugano, Italy.
1896 Acheson produces graphite in electric furnace.
1897 Marconi sends aërial messages nine miles.
1901 Hewitt mercury vapor arc light. Mercury vapor A.C. rectifier.
1901 Nernst lamp with earthy conductors.
1901 New York Central R. R. prepares for electrification.
1902 Lamme series alternating current railway motor.
1902 Birkeland and Eyde fix atmospheric nitrogen commercially.
1905 Tantalum high-efficiency incandescent lamp introduced.
1905 Osmium, wolfram and metalized carbon incandescent lamps.
1906 Osram and tungsten incandescent lamps.
1906 New York Central electric locomotives in service.
1907 Transatlantic radio-telegraphy established.

UNIT EQUIVALENTS.

(Compiled from Hering's "Conversion Tables.")

LENGTH

1 mil = 0.001 inch	0.02540005 millimeter
1 inch	2.540005 centimeters
1 foot (U. S.)	30.4801 centimeters
1 mile	1.60935 kilometers
1 centimeter (cm.)	0.3937 inch
1 kilometer	3280.83 feet

AREA

1 circular mil (CM)	0.785398 square mil
" "	0.000506709 square millimeter
1 square inch	1 273 240. circular mils
" "	645.163 square millimeters
1 square centimeter	197 352. circular mils
" "	0.155 square inch

VOLUME

1 cubic inch	16.38716 cubic centimeters
" "	0.000 578704 cubic foot
1 cubic foot	28 317. cubic centimeters
" "	7.48052 gallons (liquid U. S.)
" "	6.42851 gallons (dry U. S.)
" "	0.037037 cubic yard
1 cubic yard	46 656. cubic inches
" "	0.764 559 cubic meter
1 pint (liquid U. S.)	473.179 cubic centimeters
" "	28.875 cubic inches
" "	16. fluid ounces
" "	0.859367 dry pint
1 gallon (liquid U. S.)	3785.43 cubic centimeters
" "	231. cubic inches
" "	0.133 681 cubic foot
1 gallon (British or Imperial)	4545.9631 cubic millimeters

1 cubic centimeter	0.0610234 cubic inch
" "	0.001 liter
1 liter	61.0234 cubic inches
"	2.11336 pints (liquid U. S.)
"	1.81616 pints (dry U. S.)

WEIGHT

1 grain	0.064 799 gram
"	0.00228571 ounce avoirdupois
1 ounce (avoirdupois)	437.5 grains
" "	28.3495 grams
" "	0.0625 pound avoirdupois
1 pound (lb. avoirdupois) .	7000 grains
" "	453.5924277 grams
1 ton, 2000 pounds	907.185 kilograms
1 long ton, 2240 pounds ..	1016.05 kilograms
1 gram	15.43235639 grains
"	0.035274 ounce avoirdupois
"	.00220462 pounds avoirdupois
1 cubic centimeter water ..	1 gram
1 cubic foot water	62.4283 pounds avoirdupois
" " "	28.317 kilograms
1 gallon water (liquid U. S.)	8.34545 pounds avoirdupois
" " "	3.785 43 kilograms

ENERGY WORK HEAT

1 erg or dyne-centimeter..	0.000 0001 joule
"	0.00101979 gram-centimeter
1 gram-centimeter	980.5966 ergs
"	0.000 07233 foot-pound
1 joule, watt-second	10 197.9 gram-centimeters
" "	0.737 612 foot-pound
" "	0.101979 kilogram-meter
" "	0.000 947 96 thermal unit (B.T.U.)
" "	0.238 882 small calorie
1 calorie, large	1000 small calories
" "	4186.17 joules
" "	3087.77 foot-pounds
" "	3.968 32 British thermal units
" "	1.162 82 watt-hours
" "	0.001 559 48 horsepower-hour

1 thermal unit (British, B.T.U.)	1 lb. water 1 degree Fahrenheit
" " " "	1054.9 joules
" " " "	778.104 foot-pounds
" " " "	251.996 small calories
" " " "	1.414 74 horsepower-seconds
" " " "	0.293 027 watt-hour
1 foot-pound	1.355 73 joules
"	13 825.5 gram-centimeters
"	0.001 818 18 horsepower-second
"	0.001 285 17 thermal unit (B.T.U.)
"	0.323 859 small calorie
"	0.000 000 376 591 kilowatt-hour
1 horsepower-second	745.65 joules or watt-seconds
"	550. foot-pounds
"	178.122 small calories
"	76.0404 kilogram-meters
1 horsepower-hour	2 684 340. joules
"	745.65 watt-hours
"	1 980 000 foot-pounds
"	641.24 large calories
"	1.013 87 metric horsepower-hours
"	2544.65 thermal units (B.T.U.)
1 kilowatt-hour	3 600 000. joules, watt-seconds
"	2 655 403. foot-pounds
"	367 123 kilogram-meters
"	3412.66 thermal units (B.T.U.)
"	1.34111 horsepower-hours
"	1.35972 metric horsepower-hours

POWER, RATE OF DOING WORK

1 watt	1 joule per second
"	10 000 000. ergs per second
"	10 197.9 gram-centimeters per second
"	0.737 612 foot-pound per second
"	0.056 8776. thermal unit (B.T.U.) per minute
1 horsepower (English)	745.65 watts
" "	550. foot-pounds per second
" "	42.41 thermal units per minute
" "	10.6873 large calories per minute
" "	1.01387 metric horsepower

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(The figures refer to the numbered paragraphs.)